

Bacteria TMDLs for Cedar Run and Licking Run, Virginia

**Submitted by
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EXECUTIVE SUMMARY

Bacteria Impairment

The Virginia Department of Environmental Quality (VADEQ) listed sections of both Cedar Run and Licking Run in the Commonwealth's 2002 303(d) TMDL Priority List of Impaired Waters (VADEQ, 2002). The Cedar Run impairment was originally listed in 1996 and the Licking Run impairment was originally listed in 1998. These TMDLs focus on bacteria impairments. Based on violations of the bacteria standard recorded at Virginia Department of Environmental Quality (VADEQ) monitoring stations, the streams do not support primary contact recreation (e.g. swimming). The state standard that was applicable at the time of the 2002 assessment specified that the number of fecal coliform bacteria shall not exceed a maximum allowable level of 1,000 colony forming units (cfu) per 100 milliliters (ml) (Virginia Water Quality Standard 9 VAC 25-260-170). (The applicable standard has since been changed to an instantaneous maximum of 235 cfu of *E. coli* per 100mL.) A review of available monitoring data for the study area indicated that fecal coliform bacteria were consistently elevated above the 1,000 cfu/100 ml standard.

Sources of Bacteria

Potential bacteria sources in the Cedar and Licking Run sub-basins were assessed using multiple approaches, including information from VADEQ, Virginia Department of Conservation and Recreation (VADCR), Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Cooperative Extension (VCE), Virginia Department of Health (VDH), Fauquier and Prince William Counties Offices of Planning and GIS departments, Natural Resources Conservation Service (NRCS), Virginia Department of Agricultural and Consumer Services (VDACS), John Marshall and Prince William Soil and Water Conservation Districts, public participation, watershed reconnaissance and monitoring, published information, and professional judgment. Potential sources of fecal coliform include both point source and nonpoint source contributions. Nonpoint sources include wildlife; grazing livestock; land application of manure; land application of biosolids; urban/suburban runoff; failed or malfunctioning septic systems, and uncontrolled discharges. Permitted point source discharges in Cedar and Licking Run

include: sewage treatment plants for the US Marine Corps Base, H.M. Pearson Elementary School and Smith Midland, Inc., twelve private residences, and three Confined Animal Feeding Operations (CAFO).

Water Quality Monitoring

The TMDL development requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN, Windows Version (HSPF) was used to model fecal coliform transport and fate in the Cedar Run and Licking Creek watersheds. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model.

Hourly flows from the Occoquan Watershed Monitoring Laboratory's Cedar Run ST25 gage located at Aden Road were used for direct calibration of the model. The representative hydrologic period used for calibration ran from June 1, 1990 through December 31, 1994. The model was validated using one-hour flows recorded at the same gaging station from January 1, 1995 through June 30, 1998. The time periods covered by calibration and validation represent a broad range of hydrologic and climatic conditions and are representative of the long-term precipitation and discharge record. For purposes of modeling watershed inputs to in-stream water quality, the Cedar Run drainage area was divided into nine subwatersheds. The model was calibrated for water quality using data collected at VADEQ monitoring stations between January 1993 and December 1997, and validated using data collected between January 1998 and December 2000. All allocation model runs were conducted using precipitation data from January 1993 through December 1997. The water quality calibration was performed at an hourly time step using the HSPF model. The water quality calibration period was June 1, 1990 through December 31, 1994. Observed water quality data were obtained from the DEQ station 1ACER006.00 on Cedar Run and the DEQ station 1aLIL001.43 on Licking Run.

Existing Loadings and Water Quality Conditions

Wildlife populations and ranges; biosolids application rates and practices; rate of failure, location, and number of septic systems; domestic pet populations; numbers of cattle and other livestock; and information on livestock and manure management practices for the Cedar Run and Licking Run sub-basins were used to calculate fecal coliform loadings from land-based nonpoint sources in the watershed. Bacteria loads that are directly deposited by cattle and wildlife in streams were treated as direct nonpoint sources in the model. Bacteria that were land-applied or deposited on land were treated as indirect nonpoint source loadings; all or part of that load may be transported to the stream as a result of surface runoff during rainfall events. Direct nonpoint source loading was applied to the stream reach in each sub-watershed as appropriate. The point sources permitted to discharge bacteria in the watershed were incorporated into the simulations at the stream locations designated in the permit.

The nonpoint source loading was applied in the form of fecal coliform counts to each land use category in a sub-watershed on a monthly basis. Fecal coliform die-off was simulated while manure was being stored, while it was on the land, and while it was transported in streams. Both direct and indirect nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams.

Contributions from all of these sources were represented in the model to establish existing conditions for the watershed over a representative hydrologic period (1990-1994). Under existing conditions (2002), the HSPF model provided a comparable match to the VADEQ BST monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the watershed.

Licking Run

Analysis of the simulation results for the existing conditions in the watershed (Table E-1) show that cattle direct deposits of manure to streams are the primary source of *E. coli* in the stream, accounting for 81% of the mean daily *E. coli* in the stream. Loadings from wildlife direct deposit are the next largest contributors of *E. coli* in the stream, accounting for 12% of daily *E. coli* concentrations. Next comes pervious land

segments (manure applied to or deposited on cropland, pastures, and forests by livestock, wildlife, and other NPS sources) with 7% of the mean daily in-stream *E. coli* concentration. Nonpoint source loadings from impervious areas are responsible for less than 1% of the mean daily *E. coli* concentration.

Table E-1. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the Licking Run watershed.

Source	Mean Daily <i>E. coli</i> Concentration by Source, cfu/100mL	Relative Contribution by Source
All sources	957	100%
Direct deposits of cattle manure to stream	776	81%
Direct nonpoint source loadings to the stream from wildlife	118	12%
Nonpoint source loadings from pervious land segments	63	7%

Cedar Run

Analysis of the simulation results for the existing conditions in the watershed (Table E-2) show that direct deposits from livestock are the primary source of *E. coli* in the stream. These direct deposits account for approximately 65% of the mean daily *E. coli* concentration in the stream. Feces directly deposited by wildlife in the stream constitute the next largest contribution at 26% of the mean daily *E. coli* concentration. Contributions from the upland pervious land segments account for approximately 8% of the concentration at the watershed outlet. Runoff from impervious areas contributed less than 1% of the mean daily *E. coli* concentration.

Table E-2. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the Cedar Run watershed.

Source	Mean Daily <i>E. coli</i> Concentration by Source, cfu/100mL	Relative Contribution by Source
All Sources	808	100%
Direct deposits of cattle manure to stream	529	65%
Direct nonpoint source loadings to the stream from wildlife	213	26%
Nonpoint source loadings from pervious land segments	66	8%

Loading Allocation Scenarios

The next step in the TMDL process was to see what reductions in fecal coliform and *E. coli* loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standards for *E. coli* used in the development of the TMDL were 126 cfu/100mL (calendar-month geometric mean) and 235 cfu/100mL (single sample maximum). Scenarios were evaluated to predict the effects of different combinations of source reductions on final instream water quality. Modeling of these scenarios provided predictions of whether the reductions would achieve the target of 0% violations of the water quality standards. Periods of low flow were critical in terms of water quality.

Licking Run:

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample maximum water quality goals (Table E-3) requires a 99% reduction in direct deposits of cattle manure to streams, a 90% reduction in direct deposits by wildlife to streams, no reductions in loadings to cropland, and a 95% reduction in nonpoint source loadings to pastures. No reductions in loadings to residential land surfaces, forest or from point sources are required.

Table E-3. Reductions required by source category in the Licking Run watershed.

Source Category	Existing conditions load ($\times 10^{12}$ cfu)	Allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	127	127	0%
Pasture	7,090	355	95%
Residential	74.7	74.7	0%
Forest	150	150	0%
Total Indirect NPS	7,440	707	90%
Cattle in streams	36.7	0.367	99%
Wildlife in Streams	7.6	0.76	90%
Total Direct NPS	44.3	1.13	97%
Total PS	0.00261	0.00261	0%
Total	7,486	708	91%

Cedar Run:

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample maximum water quality goals (Table E-4) requires a 99% reduction in direct deposits of cattle manure to streams, a 95% reduction in direct deposits of wildlife feces to streams, and a 95% reduction in nonpoint source loadings to pastures and residential areas. No reductions in nonpoint source loadings to cropland or forest or in point source loadings are required. These reductions apply only to the non-Licking Run portions of the watershed; the reductions from the Licking Run successful TMDL scenario presented in Table E-3 are also required in order for Cedar Run to meet the water quality standards.

Table E-4. Reductions required by source category in the Cedar Run watershed.

Source Category	Existing conditions load ($\times 10^{12}$ cfu)	Allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	767	767	0%
Pasture	53,900	2,700	95%
Residential	1,560	78	95%
Forest	2,010	2,010	0%
Total Indirect NPS	58,200	5,560	90%
Cattle in streams	160	1.6	99%
Wildlife in Streams	100	5	95%
Total Direct NPS	260	6.6	97%
Total PS	0.122	0.122	0%
Total	58,500	5,560	90%

Margin of Safety

While developing the allocation scenarios to implement the bacteria TMDL, an implicit margin of safety (MOS) was used by using conservative estimations of the bacteria sources in the watershed (e.g., animal numbers, production rates, and contributions to streams). These factors were estimated in such a way as to represent the worst-case scenario; i.e., these factors would describe the worst stream conditions that could exist in the watershed. Creating a TMDL with these conservative estimates ensures that the worst-case scenario has been considered and that no water quality standard violations will occur if the TMDL plan is followed.

Recommendations for TMDL Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on Cedar and Licking Run. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

In the Licking and Cedar Run watersheds a number of failing septic systems have been documented over time. While the loads in by themselves do not constitute a majority of the contamination problem, they do represent a potentially serious health issue. Additionally, the majority of the systems currently installed are becoming aged and it is anticipated that left unchecked the potential for contamination will only increase with time. The staged implantation efforts should address these septic issues concurrently with the agricultural issues.

The goal of the first phase is to foster local support for the implementation plan and to reduce the violations of the instantaneous standard to no more than 10%. In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. The iterative implementation of BMPs in the watershed has several benefits:

- It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
- It provides a measure of quality control, given the uncertainties inherent in
- computer simulation modeling;
- It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
- It helps ensure that the most cost effective practices are implemented first; and
- It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Because this watershed is currently undergoing a transformation from an agricultural dominated land use pattern to an urban land use, it is anticipated that the sources of contamination will shift over time. As such the staged implementation plan will allow for flexibility in addressing the prevalent sources. Similarly within the agricultural community the prevalence of a milk based cattle population is being supplanted by a beef based population which may require different implementation efforts.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities. For Licking Run the Stage 1 Scenario requires a 99% reduction in direct deposits by cattle to streams, no reduction in loadings from cropland, and a 95% reduction in loadings from pastures. No reduction in wildlife deposits to the stream is required. For Cedar Run the Stage 1 Scenario requires a 99% reduction in direct deposits by cattle to streams, reductions (95%) in loadings from pastures and residential surfaces, and no reductions from cropland. No reduction in wildlife deposits to the stream is required.

Public Participation

During development of the TMDL for the Cedar and Licking Run, public involvement was encouraged through three meetings. A basic description of the TMDL process and the agencies involved was presented at the first public meeting. The second public meeting was held to discuss the source assessment input, bacterial source tracking,

and model calibration data. The final model simulations and the TMDL load allocations were presented during the final public meeting. Public understanding of and involvement in the TMDL process was encouraged. Input from these meetings was utilized in the development of the TMDL and improved confidence in the allocation scenarios developed.

1. Introduction

1.1 Background

Section 303(d) of the Federal Clean Water Act and the United States Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130), requires states to identify water bodies that are in violations of the water quality standards for any given pollutant. Under this rule, states are also required to develop a Total Maximum Daily Load (TMDL) for the impaired water body. A TMDL determines the maximum amount of pollutant that a water body is capable of receiving while continuing to meet the existing water quality standards. TMDLs provide the framework that allows states to establish water quality controls to reduce sources of pollution with the ultimate goal of water quality restoration and the maintenance of water resources.

The Virginia Department of Environmental Quality (VADEQ) listed both the Cedar Run and Licking Run sub-basins in the Commonwealth's 2002 303(d) TMDL Priority List of Impaired Waters (VADEQ, 2002). The Cedar Run impairment was originally listed in 1996 and the Licking Run impairment was originally listed in 1998.

1.1.1 Study Area Description

The Cedar Run and Licking Run sub-basins are part of the Occoquan River watershed located in Fauquier County and Prince William County, Virginia (Figure 1). The Occoquan River empties into the Potomac River which then empties into the Chesapeake Bay. The Cedar Run and Licking Run sub-basins are located within USGS hydrologic unit No. 02070010 and Virginia hydrologic planning units VAN-A17R and VAN-A18R. The streams flow from north west to east, with a southerly tilt. This TMDL report addresses two bacteria impairments identified by VADEQ; for Cedar Run the impairment begins at the confluence of Mill Run to Cedar Run and continues to the confluence with the Occoquan River, for Licking Run the segment begins at Route 602, below the mouth of Germantown Lake, and continues downstream to the confluence with

Cedar Run. Total combined drainage for the two sub-basins is approximately 125,000 acres or 195 square miles.

1.2 Impaired Water Quality Status

VADEQ determined that Cedar and Licking Run exceeded one of the existing instream fecal coliform water quality standards and identified the source of impairment as being “unknown”. Fecal coliform bacteria are the primary resident bacteria in the feces of all warm-blooded animals. Although not usually pathogenic, fecal coliform bacteria are commonly used as an indicator for potential health risks resulting from pathogenic organisms that are also known to reside in feces. The Cedar and Licking Run watersheds have been given a TMDL status of “medium priority” resulting from the Virginia Water Quality Assessment for 2000 and a high NPS ranking in VADEQ’s 2000 305(b) report to Congress and EPA.

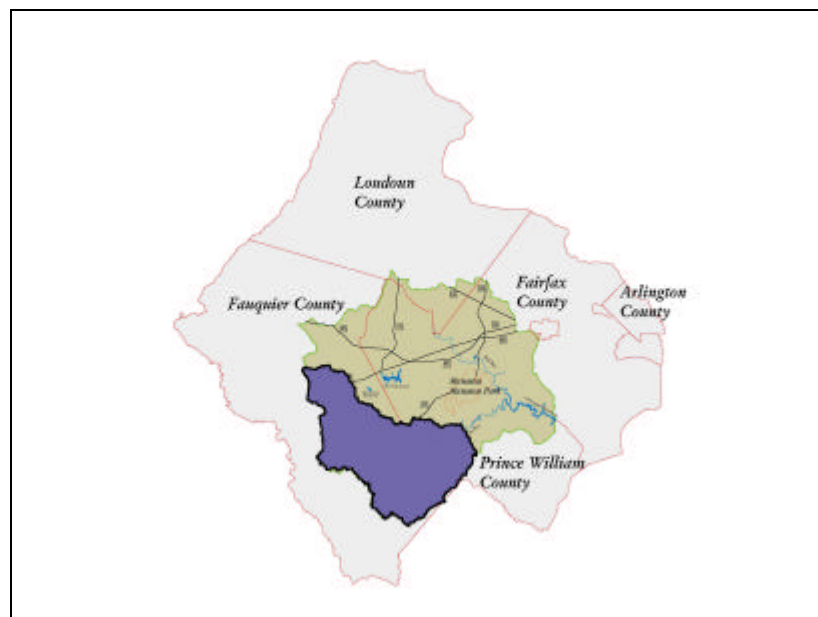


Figure 1. Location of Cedar Run Watershed

1.3 Applicable Water Quality Standard

According to Virginia Water Quality Standards (9 VAC 25-260-5),

“water quality standards means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.).”

1.3.1 Designated Uses

According to Virginia Water Quality Standards (9 VAC 25-260-10A),

“all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish).”

1.3.2 Applicable Water Quality Criteria

Following EPA guidance, VADEQ has adopted new bacteria criteria for *Escherichia coli* (*E. coli*) bacteria to replace the previously used fecal coliform criteria for fresh water. EPA recommended the States' adoption of these standards because there is a stronger correlation between the concentration of *E. coli* and the incidence of gastrointestinal illness than with fecal coliform bacteria. *E. coli* are a subset of fecal coliform bacteria and can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination.

The new bacteria criteria became effective on January 15, 2003. While violations of the previous fecal coliform criteria led to the impairment listings of Cedar Run and Licking Run, the new *E. coli* criteria will be the target for the TMDL calculations and must be met in the model scenarios. The previous fecal coliform criteria (listing criteria) and the new *E. coli* criteria (TMDL target) are described below:

Former criteria (fecal coliform bacteria)

For a non-shellfish supporting waterbody to be in compliance with Virginia bacteria standards for primary contact recreational use, VADEQ specifies the following criteria (9VAC 25-260-170):

“...the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more

samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 mL at any time.”

Both Cedar Run and Licking Run exceeded the instantaneous criterion of 1,000 per 100 ml more than 10% of the time which resulted in their identification as impaired waters.

New criteria (fecal coliform bacteria and E. coli)

The *E. coli* criteria for freshwater are a geometric mean of two or more samples taken during any calendar month of no more than 126 cfu/100mL, and an instantaneous single sample maximum of 235 cfu/100mL. These criteria became applicable to all freshwater sampling stations on January 15, 2003. Fecal coliform criteria will remain in effect only until a minimum of 12 *E. coli* data points have been collected or June 30, 2008, whichever comes first. While the fecal coliform bacteria water quality standard is still in effect, it has been changed to read:

“Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water.”

It is important to note that in the former bacteria standards, either the geometric mean or the instantaneous criterion is applied, depending on the sampling frequency. In the new standards, both the geometric and the instantaneous criteria apply to data sets with two or more samples collected per month. Only the instantaneous criterion applies when one or fewer samples are collected per month. That is the case for ambient water quality monitoring.

However, since the computer simulation used to develop the TMDL provides daily fecal coliform concentrations (which is analogous to daily sample collection), the Cedar and Licking bacteria TMDLs are required to meet both the instantaneous criterion and the 30-day geometric mean criterion. The TMDL development process also must account for seasonal and annual variations in precipitation, flow, land-use, and pollutant contributions. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect fecal coliform loading.

1.3.3 Goal and Objectives

The goal of the Cedar and Licking Run TMDL is to allocate the sources of fecal coliform contamination and to incorporate practices that will reduce fecal coliform loads and allow Cedar and Licking Runs to meet Virginia state water quality standards. The following objectives must be completed in order to achieve this goal:

- **Objective 1**—Assess the water quality and identify the potential sources of fecal coliform
- **Objective 2**—Quantify current fecal coliform loads and estimate the magnitude of each source
- **Objective 3**—Model and predict the current fecal coliform loads being deposited from each source
- **Objective 4**—Develop allocation scenarios that will reduce fecal coliform loads
- **Objective 5**—Determine the most feasible reduction plan that can realistically be implemented and incorporate it into the TMDL.

2. Watershed Characterization

2.1 Climate

The Cedar Run and Licking Run sub-sheds are located in the Mid-Atlantic piedmont province approximately 25 miles east of the Blue Ridge Mountains, and 50 miles west of the Chesapeake Bay. Watershed elevations range from approximately 150 feet to 800 feet above mean sea level (Figure 2). Cedar Run and Licking Run are tributaries of the Occoquan River Reservoir, a primary source of raw drinking water to the northern Virginia metropolitan area. The primary sources for information presented throughout this section are documents and records from the National Weather Service (NWS) and the Occoquan Watershed Monitoring Laboratory (OWML) and the Northern Virginia Regional Commission (NVRC).

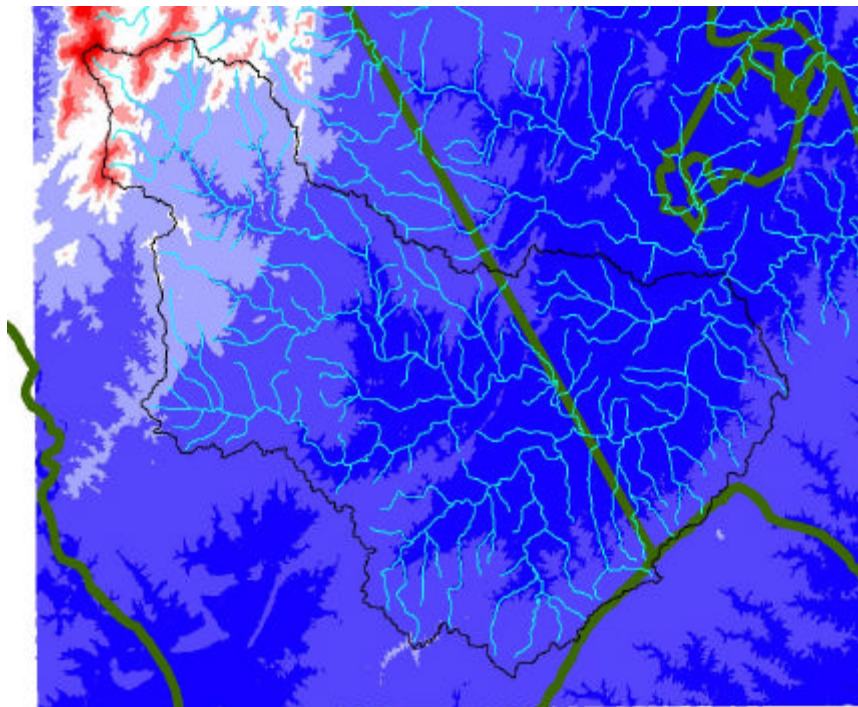


Figure 2. Digital Elevation of the Cedar and Licking Run Study Area.

Climate data for this area has been kept sporadically by NWS since 1954 at Warrenton (1954- 2000), Sterling/Dulles International Airport (1977- present) and the Reagan National Airport (1941-present). One common aspect to the airport NWS

stations is that they are located well outside of the study area (Figure 3). As part of the ongoing Occoquan Watershed Monitoring Program (OWMP) performed under the auspices of the OWML, this issue is being addressed by the installation of numerous rainfall monitoring stations to more accurately quantify the spatial distribution of rainfall throughout the basin. One of those stations was put into place within the Cedar Run sub-basin in 2001. The other monitoring station operated by the OWML Program is at the laboratory facility located within the City of Manassas. While this station is also located outside of the study area boundaries it became particularly important to this study because of its capabilities to provide sub-hourly meteorological measurements.

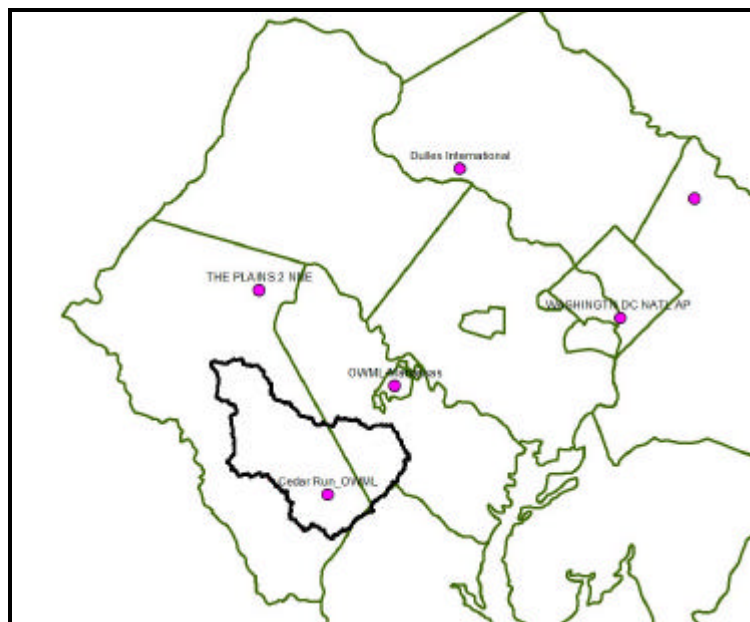


Figure 3. Location of Metrological Monitoring Stations

Winters are usually mild, with an average temperature in the mid 20's (°F). Spring and fall are generally mild climates, with very pleasant weather. Summers can be hot and humid, with temperatures averaging about 80°F. The average date of the last freeze in spring is April 1, and the average date for the first freeze in the fall is November 10.

Precipitation is generally evenly distributed throughout the year, with an annual rainfall of 38 inches per year. Historical records for the basin have shown a distribution as follows: 9.1 inches in winter; 11.1 inches in spring; 9.9 inches in summer; and 7.7

inches in the fall (NVRC, 1994). Recent years have seen substantial variations in rainfall, both seasonally and annually; near record high and lows were observed during the study period utilized for the TMDL development. Snowfalls average 18 inches per year, with perhaps only one or two major snowfalls in a season. It is unusual to have a snowstorm of 10 inches or more within any one particular day. However, there have been rare occurrences of 25-inch snowstorms.

Late spring and summer afternoons can bring locally intense thunderstorms with occasionally significant local urban flooding. Late summer can bring tropical storms or hurricanes, with their accompanying heavy rains, high winds, and flooding. Winds of up to 100 mph and rainfall exceeding seven inches have occurred with these types of storms. The greater Washington, DC metropolitan area is also subject to rare tornadoes and springtime hailstorms, both of which can result in significant damage.

2.2 Geology and Soils

The Cedar and Licking Run sub-basins lie within the Piedmont physiographic region. The Piedmont of Virginia extends eastward from the Blue Ridge to the Fall Line, where Paleozoic-age and older igneous and metamorphic rocks are covered by unconsolidated sediments of the Atlantic Coastal Plain. The Virginia Piedmont is part of the greater southeastern Piedmont, which extends from northeastern Alabama through Georgia, South Carolina, North Carolina, Virginia, Maryland, and southeastern Pennsylvania. The Piedmont is characterized by deeply weathered, poorly exposed bedrock and a high degree of geological complexity (<http://www.geology.state.va.us/DOCS/Geol/pied.html>).

Soils for the Cedar and Licking Run sub-basins were documented utilizing the VA State Soil Geographic Database (STATSGO). Three general soil types were identified using this database. Descriptions of these soil series were derived from queries to the USDA Natural Resources Conservation Service (NRCS) Official Soil Series Description web site (<http://ortho.ftw.nrcs.usda.gov/cgi-bin/osd/osdname.cgi>). Figure 4 shows the location of these general soil types in the watershed.

The Catoctin series (VA006) consists of moderately deep, well drained soils with moderately rapid permeability. They formed in material weathered primarily from greenstone. They are on nearly level to very steep ridges and side slopes. The Braddock-Dyke series (VA012) consists of very deep, well drained, and moderately permeable soils formed in colluvium and alluvium derived dominantly from a mixture of crystalline rocks. They are on footslopes of ridges and colluvial fans and adjacent high terraces. Soils of the Buckhall–Occoquan series (VA013) are very deep, well drained with moderate permeability. They formed in residuum that weathered from granite gneiss and schist of the Northern Piedmont Plateau. Soils of the Calverton series (VA015) are deep, moderately well and somewhat poorly drained. Permeability is slow or very slow. They formed on uplands in the weathered product of shale, siltstone, and some sandstone. Soils of the Catlett series (VA022) are shallow and well drained. They formed in weathered products of dark gray to brown Jurassic and Triassic hornfel and granulite. These soils are on upland ridgetops and sideslopes in the Culpeper Basin of the Northern part of the Piedmont Plateau.

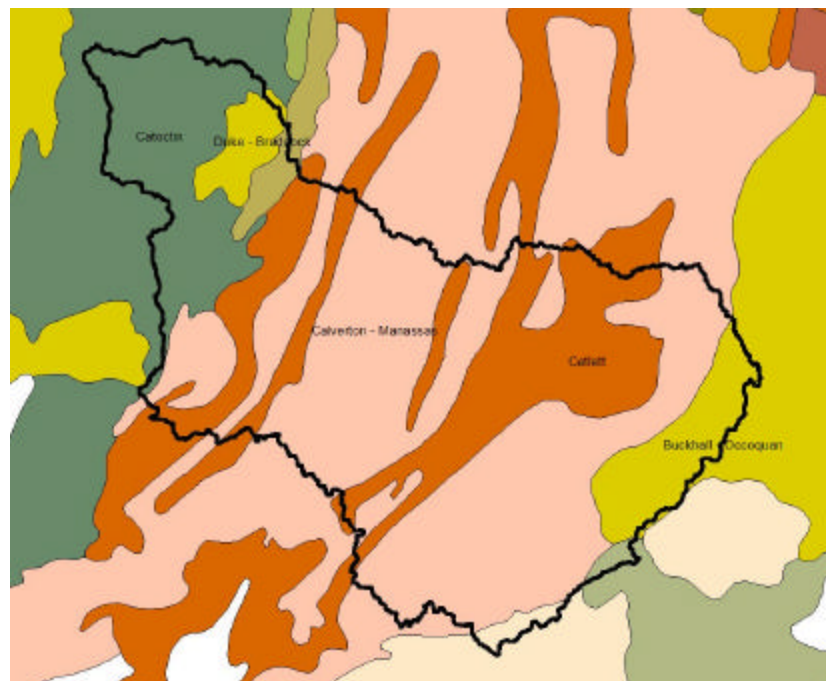


Figure 4. General Soil Map for Cedar and Licking Run

2.3 Land Use

Land use is a predominant determining factor for sources and deposition of fecal coliforms. For example, wildlife is more common in forest and open space corridors than highway corridors and high-density development. Likewise, pet populations are associated with residential lands more so than commercial or industrial areas.

Land use information was obtained from NVRC's own Occoquan Watershed land use GIS layer with a multi-jurisdictional 15-key land use classification. Land use tracking began in the late 1970's when a series of satellite images for the watershed were translated and transferred, by hand, to a mylar map. The 2000 land use data supplied by NVRC consists of land use polygons that were delineated by NVRC staff from airborne true color photography at a nominal scale of 1:40,000, taken during leaf-off conditions, with airborne photo centers and ground points identified by differential GPS during flight. The resulting digital orthophotography was produced at a map scale of 1:12,000 (1"=1,000'), at a ground resolution of 0.6m (2 foot), using a minimum mapping unit of 300m².

For the purposes of land use tracking, development within the basin is aggregated into the following urban development classifications: Estate Residential (<0.2 du/acre), Low Density Residential (0.5-2.0 du/acre), Medium Density Residential (3-6 du/acre), Townhouse/Garden Apartments (6-20 du/acre), Commercial, Industrial, and Institutional. Agricultural land use classifications are based upon the farming practice utilized: conventional tillage, mixed conventional tillage, minimum tillage, mixed minimum tillage, and livestock and pasture. Specific land use locations are shown in Figure 5.

Due to some limitations of the TMDL modeling package, some of the land use categories were aggregated for the actual model input data set; they were: forest and idle lands, livestock and pasture, agricultural tillage, low-density residential and urban lands. Table 1 shows the acreage of each existing land use by County.

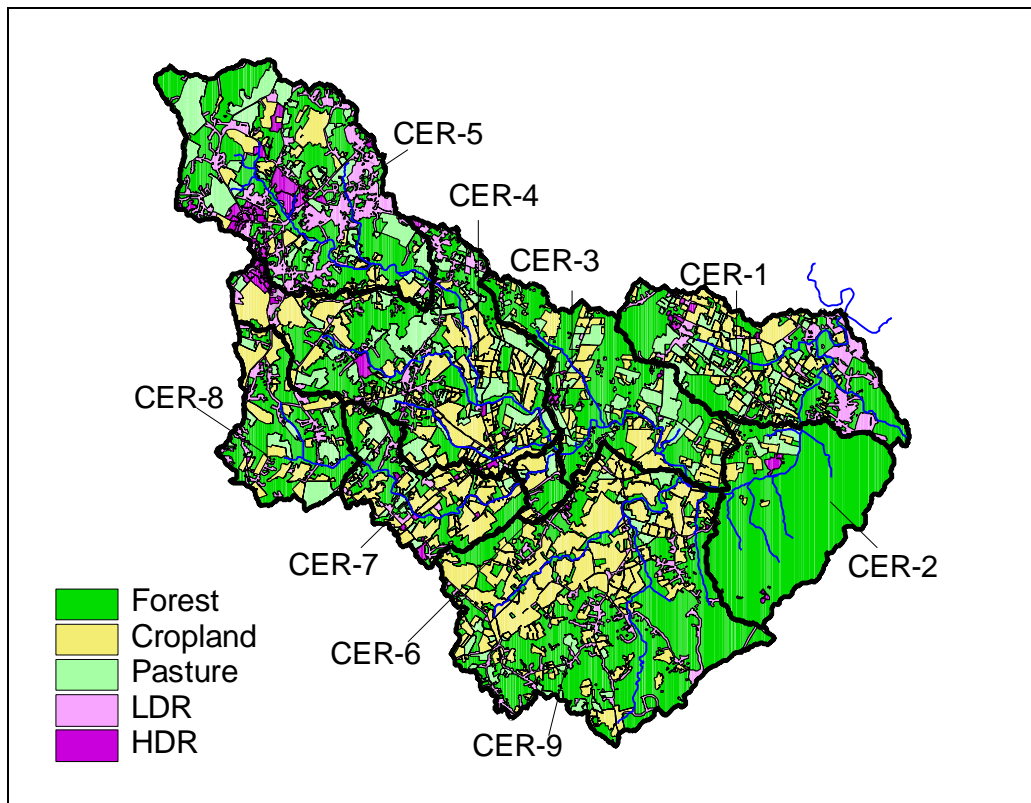


Figure 5. Land use in the Cedar and Licking Run TMDL study area

Table 1. Land Use in the Cedar and Licking Run Sub-basins.

	Cedar Run			Licking Run
	Fauquier	Prince William	Total	Fauquier Only
Urban Lands:				
Low Density Residential	2,662	3,009	5,671	751
Medium Density Residential	207	0	207	
Townhouse	24	0	24	
Commercial	157	38	196	39
Industrial	212	0	212	101
Institutional	96	258	354	
Agricultural Lands				
Livestock and Pasture	6,630	17,178	23,808	2,336
Agricultural Tillage	18,835	5,021	23,856	6,399
Forest and Idle			32,596	6,745
Total Segment Size			86,923	16,370

2.4 Historical Water Quality Data

Water quality data used for the development and analysis of this TMDL were compiled from monitoring information collected by the Virginia Department of Environmental Quality (VADEQ). The VADEQ fecal coliform data have been collected at least yearly and at most monthly at four stations in the Cedar Run portion of the study area since 1991. These stations can be seen in Figure 6. The stations are identified by the river miles above the mouth, thus ACER025.25 is a Cedar Run monitoring station located 25.25 miles above the confluence of Cedar Run and the Occoquan River. Located adjacent to ACER006.00, the OWML monitoring station ST20 has been in operation since 1987. This station is operated as part of a network of stream gaging stations which provides monitoring information for the measurement of constituent fluxes into the Occoquan Reservoir. While this station did not provide fecal coliform data, it did provide the stream flow information that was used to calibrate the TMDL model.

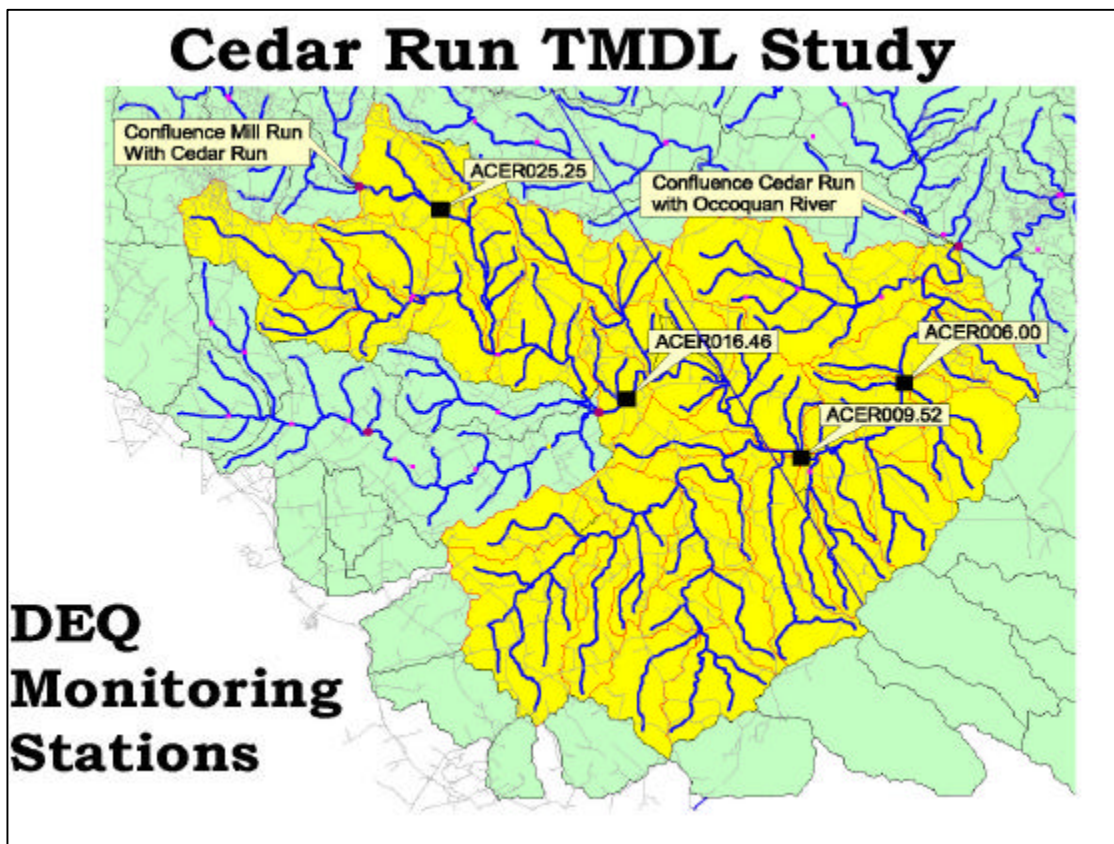


Figure 6. Cedar Run Monitoring Stations

A single fecal monitoring station (1ALIL001.43) was used to identify the Licking Run impairment (Figure 7). This station is located at the Route 616 bridge and is approximately 1.4 miles above the confluence of Cedar Run. A second station 1ALIL008.23 was established to provide biological source tracking information which will be discussed in Chapter 3. The complete fecal coliform data sets used for the impairment listing for each individual monitoring station are provided in Appendix J. Table 2 provides a summary of the fecal coliform standard violations frequency in the Cedar and Licking Run sub-basins for the period 1991-2002.

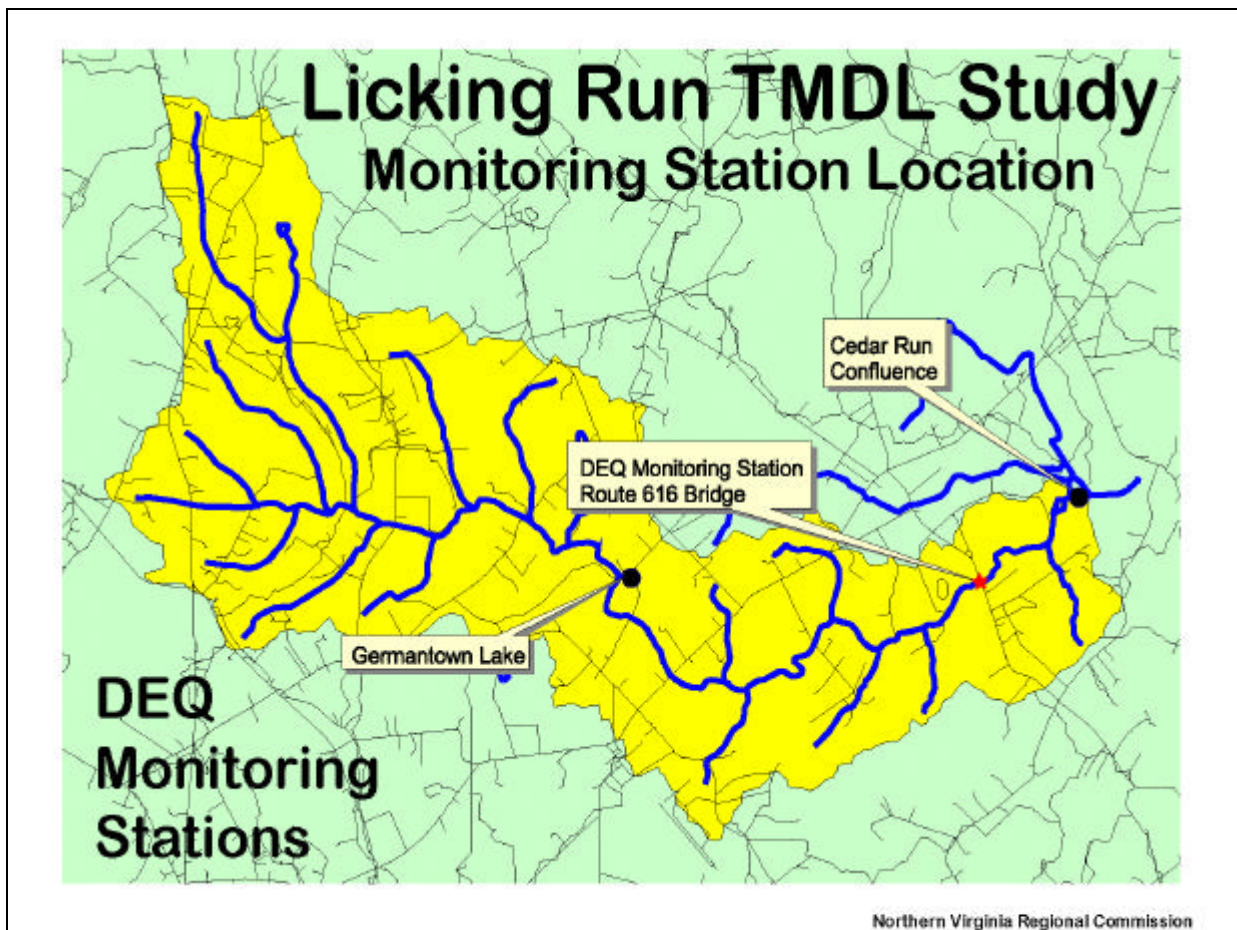


Figure 7. Licking Run Monitoring Stations

Table 2. Fecal Coliform Standard Violations Frequency

Station	Location(s)	Period Of Record	# of Observations	Frequency of Violations for Instantaneous Standard ¹
ACER006.00	Cedar Run at Route 646 Bridge	1991-2002	99	18%
ACER009.52	Cedar Run at Route 611 Bridge	1999-2000	11	27%
ACER016.46	Cedar Run at Route 806 Bridge	1991-2002	45	18%
ACER025.25	Cedar Run at Route 602 Bridge	1991-2001	38	24%
1ALIL001.43	Licking Run at Route 616 below Germantown Lake	1991-2002	40	24%

¹1,000 counts (most probable number) per 100 mL of stream water

2.4.1 Seasonal Analysis

Seasonal variation analysis for in-stream fecal coliform concentration was performed for each Cedar Run monitoring station. The seasonal cutoffs used in this analysis were the actual calendar dates for each season, and were not rounded by month. Thus, data collected on different days of a month that straddled two seasons was split between these seasons. Figure 8 presents these seasonal median values for the VADEQ monitoring stations on Cedar Run. Results show that median fecal coliform concentrations are below the instantaneous standard for all of the monitoring stations for all seasons with the exception of ACER009.52 in the Spring. Caution however should be used in evaluating this station's results due to the extremely low number of observations.

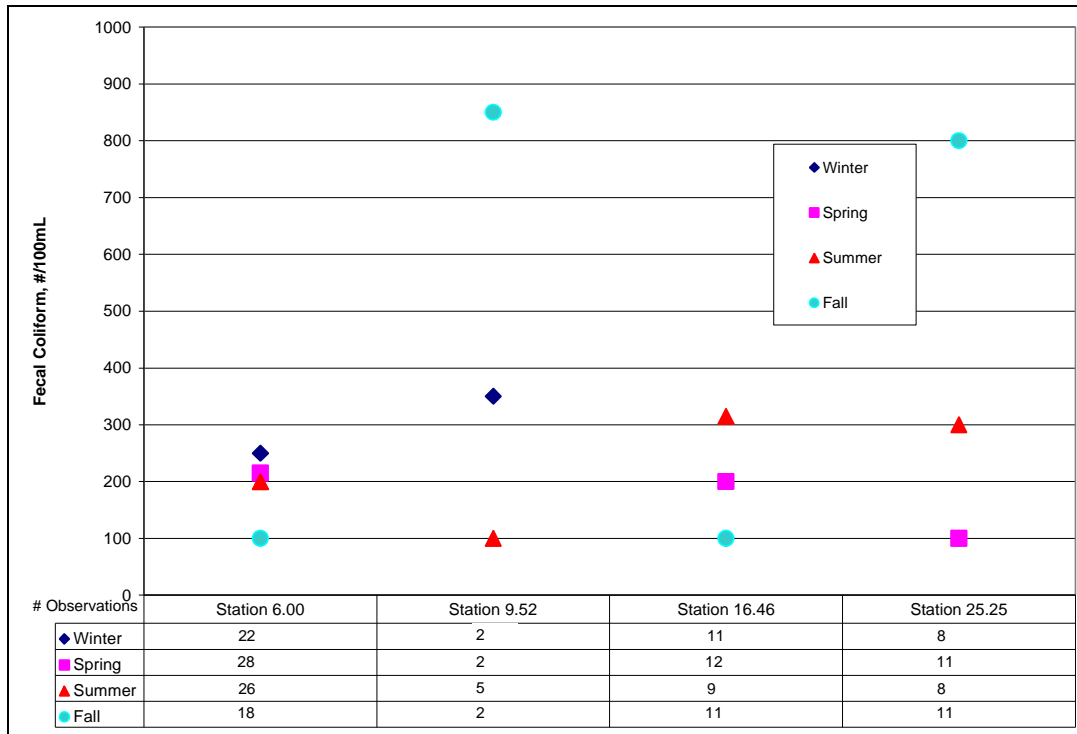


Figure 8. Seasonal Monitoring Analysis of Cedar Run Sampling Data

A simple analysis of these data for the most part indicates that there is little variation in the fecal coliform counts on a seasonal basis. When all the sampling station data are aggregated together, variations with season become even weaker. Taking into account the frequency of violations (Table 2) and a seasonal analysis showing median values consistently below the instantaneous standard, an intuitive concept can be developed that the watershed is susceptible to sporadic pulse events.

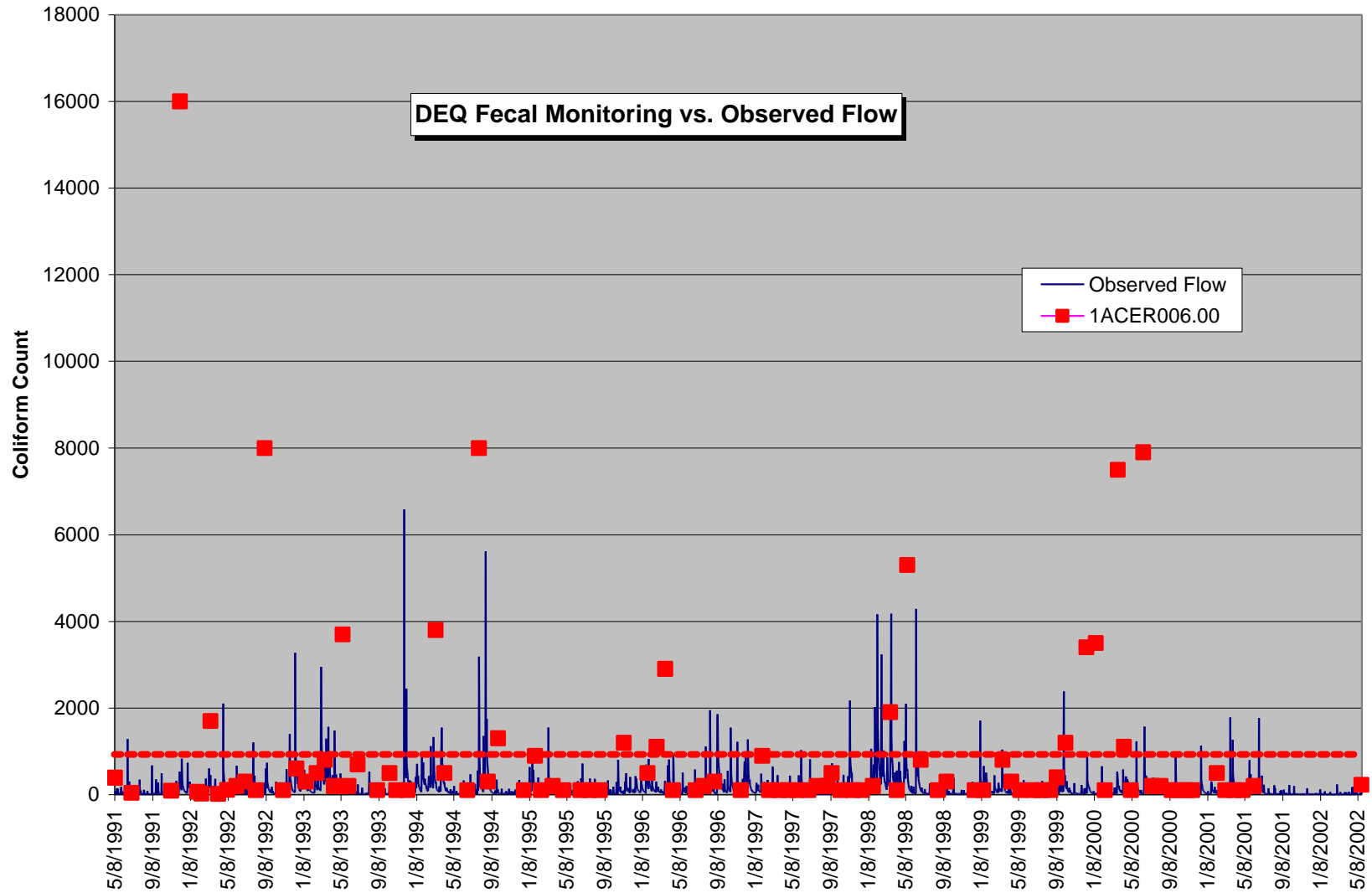


Figure 9. Observed fecal coliform counts and Cedar Run flow data for Station 1ACER006.00

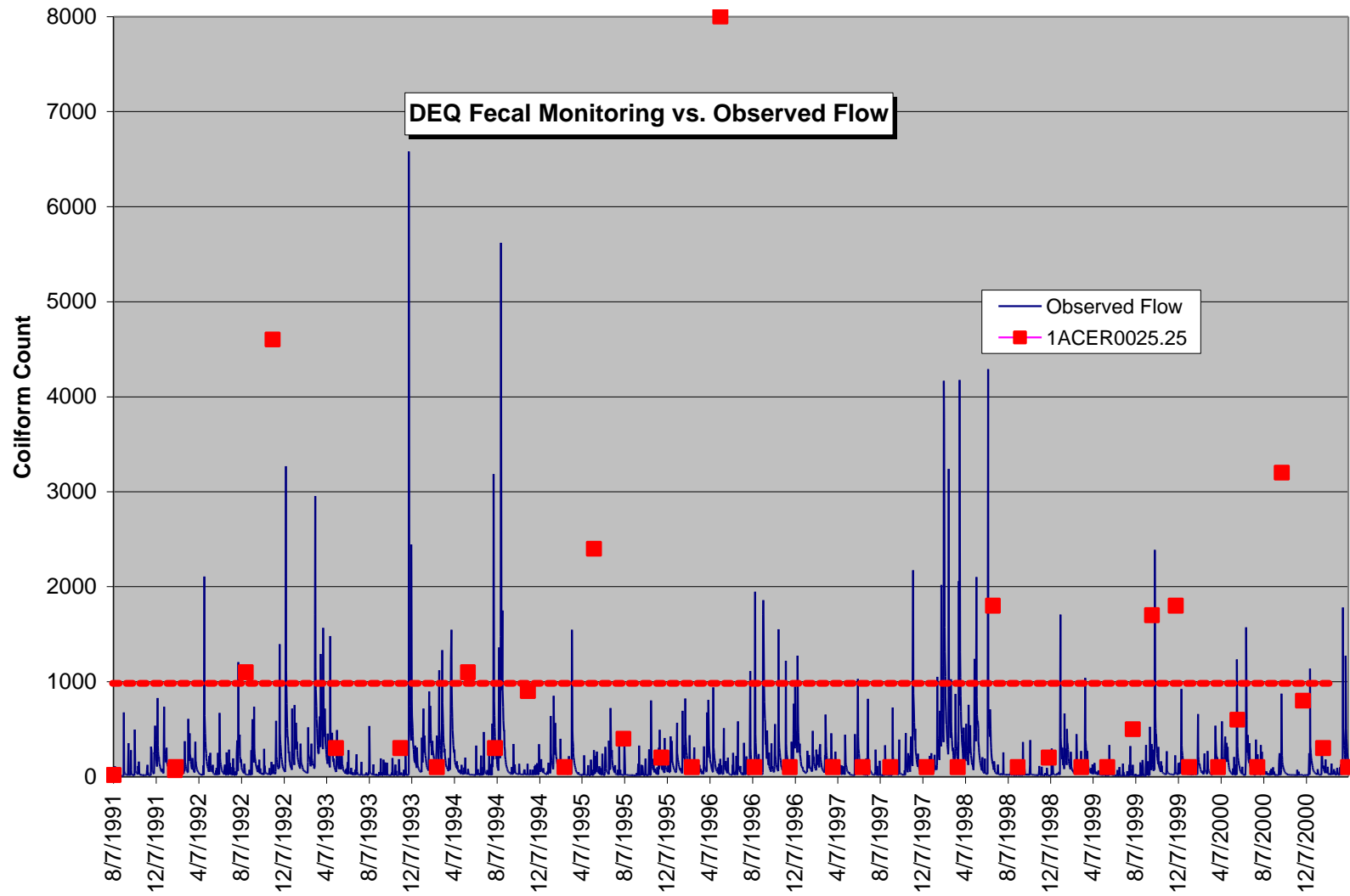


Figure 10. Observed fecal coliform counts and Cedar Run flow data for Station 1ACER025.25

3. Bacteria Source Assessment

Potential bacteria sources in the Cedar and Licking Run sub-basins were assessed using multiple approaches, including information from VADEQ, Virginia Department of Conservation and Recreation (VADCR), Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Cooperative Extension (VCE), Virginia Department of Health (VDH), Fauquier and Prince William Counties Offices of Planning and GIS departments, Natural Resources Conservation Service (NRCS), Virginia Department of Agricultural and Consumer Services (VDACS), John Marshall and Prince William Soil and Water Conservation Districts, public participation, watershed reconnaissance and monitoring, published information, and professional judgment. The gathered information was used to estimate source populations and their associated bacteria loads throughout the Cedar and Licking Run sub-basins, forming the basis for model development and analysis of allocation scenarios (Table 3).

Table 3. Source Categories.

Source Category	Source / Animal Type
Human and Pets	Permitted Discharges
	Failing Septic Systems
	Straight Pipes
	Biosolids Applications
	Dogs /Cats
Agricultural	Dairy Cattle
	Beef Cattle
	Horses
	Other Livestock
Wildlife	Deer
	Raccoon
	Muskrats
	Beavers
	Turkeys
	Waterfowl

3.1 Microbial Source Tracking (Genetic Fingerprinting)

The assessment of sources in bacteria TMDL studies involves estimating loads from sources in the watershed and developing a computer model to establish the links between estimated loads and actual in-stream bacteria concentrations. This method of source identification is verified through microbial source tracking (MST). MST methods that specifically use bacteria as the target organism are referred to collectively as bacteria source tracking (BST) methods. MST has been applied to study the microbial ecology of environmental systems for years and is now being applied to help improve water quality by identifying problem sources and determining the effect of implemented remedial solutions. Management and remediation of water pollution would be more cost effective if the correct sources could be identified (Simpson, 2002).

MST methods can be divided into three categories: molecular (genotype), biochemical (phenotype), and chemical. Molecular methods may offer the most precise identification of specific types of sources but are limited by high per-isolate costs and detailed and time-consuming procedures. They are not yet suitable for assaying large numbers of samples in a reasonable time frame. Biochemical methods of BST may or may not be as precise, but are simpler, quicker, less costly, and allow large numbers of samples to be assayed in a short period of time (Hagedorn, 2002).

Several biochemical BST methods are in various stages of development. Among these are Antibiotic Resistance Analysis (ARA), F-Specific (F+ or FRNA) Coliphage, Sterols or Fatty Acid Analysis, Nutritional Patterns, and Fecal Bacteria Ratios. Of these, ARA has been chosen as the BST method for this TMDL report.

As part of the Cedar and Licking Run TMDL development, a BST study was conducted by the VADEQ. BST samples were collected on a monthly basis at each of the DEQ monitoring stations as well as at an additional station on Licking Run above Germantown Lake (1ALIL008.23). The BST analysis was performed by MapTech, Inc. as a separate study. The results of the BST analysis provide for a measure of the relative contribution of bacteria sources to the bacteria concentration found in the water samples.

The bacteria sources were lumped into four categories: wildlife, human, livestock, and pet. A summary of the data can be found in Table 4, and the detailed data results from the BST study are included in Appendix K. Some level of caution should be utilized when reviewing the data in that this study only represents a brief glimpse of bacteria concentration in the sub-basins and may not be representative of long-term conditions in the stream.

Table 4. Summary Data for BST Study for Cedar and Licking Run.

STATION ID	Presence in Sample			
	Wildlife	Human	Livestock	Pet
1ACER006.00	80%	30%	80%	90%
1ACER009.52	80%	20%	90%	90%
1ACER016.46	82%	45%	73%	82%
1ACER025.25	83%	25%	100%	67%
Cedar Overall	81%	30%	86%	81%
1ALIL001.43	82%	18%	91%	45%
1ALIL008.23	90%	30%	100%	82%
Licking Overall	86%	24%	95%	67%

The results of the Maptech analysis indicate that the majority of the bacteria are coming from anthropogenic sources. Approximately 70% of the bacteria found in both Cedar and Licking Runs comes from human, pet, or livestock sources

Fecal coliform and *E. coli* enumerations were also performed on the BST samples. These data can also be found in Appendix L. For Cedar Run thirty-three percent of the samples exceeded both fecal coliform and *E. coli* standards; for Licking Run twenty seven percent of the samples exceeded both fecal coliform and *E. coli* standards.

In addition to the VADEQ BST study, an additional independent study was undertaken by Prince William County under the direction of Dr. Charles Hagedorn of Virginia Tech's Department of Crop and Soil Environmental Sciences. A subset of the monitoring data is presented in Tables 5 and 6.

Table 5. Number of times the *E. coli* standard was exceeded on a per sample basis.

	Number of Times Standard Exceeded			% of Samples Exceeding Std
	July - Sept	Oct. – Jan	Total	
1. Cedar Run	2	2	4	57.1
2. Slate Run	2	3	5	71.4
3. Slate Run	3	4	7	100.0
4. Slate Run	2	3	5	71.4
5. Cedar Run	1	0	1	14.3
6. Cedar Run	1	1	2	33.3
7. Cedar Run	2	2	4	57.1

Table 6. Number of times the *E. coli* standard was exceeded on a per stream basis.

Sample #	Stream	Total No of Samples	No. of Times Standard Exceeded	% of Samples Exceeding Std
3, 7-9	Cedar Run	27	11	40.7
4-6	Slate Run	21	17	81.0

The results of this testing indicated some contradictions to the VADEQ study. In the County's Cedar Run samples, wildlife, human, livestock, and bird signatures were all found, but there was no signature for pets. The lack of a pet signature contrasts sharply with the DEQ study. The source allocations were fairly evenly divided among the four sources, and no single source emerged as the dominant source. This fairly even distribution of sources is typical of larger streams and is indicative of the many mixed land uses that occur in the watershed that surrounds Cedar Run. In Slate Run, as with Cedar Run, wildlife, human, livestock, and bird signatures were all found, but again no pet signatures. Livestock emerged as the dominant source in Slate Run, with wildlife as the second largest signature. The human signature was persistent and larger than the human signature found in Cedar Run, while the bird signature is minor in Slate Run (Prince William County, 2004)

The discrepancy appears to be a result of how the two laboratories analyze the samples against known source libraries. The Prince William contractors libraries contained an unknown category and all bacterial isolates that are classified by source at less than 80% probability are put into this unknown category. This is a new development

in BST analysis, and is not in wide spread use at present. However, based on two national-level method comparison studies and recent reviews of the use of BST by EPA, it is clear that there are benefits in analyzing the results in this fashion. There is no hard reason for using 80%, and other investigators have used values from 50% to over 90%. For the 10 samples from site 1ACEROO6.00 that MapTech performed BST on, 24 *E. coli* isolates were analyzed for 9 of the samples, and 21 for one sample, for a total of 237 isolates. When all those that were classified at a probability of less than 80% were removed, the results are as follows: Unknown 46%, Pets 9.3%, Livestock 22.4%, Wildlife 19.8%, and Human 2.5%.

The loss of almost half of the isolates when the unknown category is added is typical of what has been published to date. There is no way that a library will be completely representative of all sources in a watershed without building a truly giant library (and even that may not work). The above results indicate that livestock and wildlife are the dominant sources, with a minor pet signature, and a very small human signature.

Taken in this context, the results are similar to those reported from the separate PWC study. The pet signature is still larger than what was reported by the PWC, but that may be due to what is included in the pet category. The PWC contractor's library contains dogs only, while the DEQ—MapTech library includes cats as well. At issue is that cats' bury their waste; they consume small mammal or bird they can catch, and then obtain a large dose of *E. coli* from their prey when it is consumed. It is possible that this may give rise to confusion between wildlife/bird and pet categories. (Hagedorn, 2004)

3.2 Humans and Pets

3.2.1 Permitted Discharges

Virginia Pollutant Discharge Elimination System (VPDES) permits were reviewed to determine if any facilities discharge within the Cedar and Licking Run sub-basins. Table 7 presents a listing of those permitted facilities. Permitted point source discharges in the sub-basins include; sewage treatment plants for the US Marine Corps Base, H.M.

Pearson Elementary School and Smith Midland, Inc., twelve private residences and three Confined Animal Feeding Operations (CAFO).

Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml (*E. coli* below 126 cfu/100mL). One method for achieving this goal is chlorination. Chlorine is added to the discharge stream at levels intended to kill off any pathogens. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. If the concentration is high enough, pathogen concentrations, including fecal coliform and *E. coli* concentrations are considered reduced to acceptable levels. Typically, if minimum TRC levels are met, fecal coliform concentrations are reduced to levels well below the 200 cfu/100 ml limit. In allocation scenarios for bacteria, the entire allowable point source discharge concentration of 200 cfu/100 mL was used (126 cfu/100mL for *E. coli*).

Current EPA guidance requires a bacterial waste load allocation to be determined for MS4 permits. In three previous bacteria TMDLs (Accotink Creek, Four Mile Run, and Lynnhaven Bay) DEQ estimated MS4 bacterial waste load allocation by the % impervious portions of urban land use area. Note that the TMDL does not directly model the MS4 bacterial waste load allocation, but derives a gross estimate of the MS4 waste load allocation. The Prince William County portion of the Cedar Run sub-basin is permitted under a VPDES Phase 1 MS4 Permit. Percent imperviousness for urban land in that portion of Cedar Run was determined from land use information presented in Chapter 4. The total acres of the watershed within Prince William County are approximately 26,000 acres. The acres of these urban land uses were multiplied by the respective % imperviousness, and the resulting impervious acres were totaled to calculate the MS4 waste load allocation.

Table 7. Permitted Point Sources in the TMDL study area.

Permit Number	Facility	Flow (MGD)	Permitted FC Conc.	Permitted FC Load (cfu/year)	Allocated FC Load (cfu/year)	Allocated <i>E. coli</i> Load (WLA) (cfu/year)
VA0028371	US Marine Corps - Quantico	0.04	200 cfu/100 mL	1.11E+11	1.11E+11	6.97E+10
VA0027278	Pearson Elementary	0.0079	200 cfu/100 mL	2.18E+10	2.18E+10	1.38E+10
VA0084298	Smith Midland Incorporated	0.0015	200 cfu/100 mL	4.15E+09	4.15E+09	2.61E+09
VAG406075	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406089	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406090	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406091	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406108	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406126	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406188	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406192	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406210	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406267	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406317	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406323	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09

Permit Number	Facility	Flow (MGD)	Permitted FC Conc.	Permitted FC Load (cfu/year)	Allocated FC Load (cfu/year)	Allocated <i>E. coli</i> Load (WLA) (cfu/year)
VA0088595 and VAR040100	MS4 Permits	NA	NA	NA	5.25E+11 ^a	4.52E+11 ^a

^a The MS4 portion of the WLA was determined by ‘turning off’ all bacteria sources in the model other than those coming from the impervious surfaces in the MS4 areas; the resulting model output concentration timeseries was multiplied by the output flow timeseries to yield a load timeseries that was averaged to represent an annual load and included here.

Additionally, two municipal separate storm sewer system (MS4) permits have been issued in the Cedar Run watershed for Prince William County (VA0088595) and Prince William County Schools (VAR040100). These permits are designed to compel awareness of the quality of water discharging from publicly owned storm sewer outfalls, and to reduce pollution from the MS4, although no numerical limits for any specific water quality parameter are stipulated in these permits. The permits blur the lines that have traditionally distinguished point and nonpoint sources of pollution. While the MS4 permits are regulated similarly to point source discharges, water quality discharging from the MS4s is nearly exclusively dictated by nonpoint source runoff (along with an unknown, but presumed small, amount of illicit connections). Fecal coliform loads modeled from impervious areas within the MS4 areas are included in the wasteload allocation (WLA) component of the TMDL, in compliance with 40 CFR §130.2(h). Fecal coliform loads related to stormwater runoff from areas covered by MS4 permits were modeled with HSPF as contributions from impervious land use categories. Because the Schools’ permit covers part of the area already covered by the County permit, a single allocation was developed and assigned jointly to the two permits.

3.2.2 Assessment of Nonpoint Sources

In order to gain an understanding of non-point source loadings in the Cedar and Licking Run sub-basins, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources include residential sewage treatment systems, straight pipes, livestock, wildlife, and pets. Sources were identified and enumerated. Estimates were

based upon animal and human population data sets, typical waste production rates and typical bacteria densities in waste products. Where appropriate, spatial distribution of sources was also determined.

Currently values for fecal bacteria production rates are primarily published in terms of fecal coliform. Very little data on *E. coli* production is available; however, studies have shown that though minor variability will exist between sources, *E. coli* represents roughly 90-95% of fecal coliforms contained in "as-excreted" fecal material. It is important to note that the bacteria loads presented in the following sections on non-point sources represent "as-produced" loads. This is to say that some portion of an estimated load may not be available to be transported to the streams in runoff.

3.2.3 Humans and Pets

The Licking Run watershed has an estimated population of 2,190 people (780 households at an average of 2.81 people per household; actual people per household varies by sub-watershed, Table 8). The Cedar Run watershed has an estimated population of 20,629 people (7,646 households at an average of 2.70 people per household; actual people per household varies by sub-watershed, Table 9.)

A dog produces fecal coliform at a rate of 0.45×10^9 cfu/day (Weiskel et al., 1996); this was assumed to be representative of a 'unit pet' – one dog or several cats. The pet population distribution among the sub-watersheds for Licking Run is listed in Table 8. The pet population distribution among the sub-watersheds for Cedar Run is listed in Table 9. Pet waste is generated in the farmstead, rural residential, and urban residential land use types. Surface runoff can transport bacteria in pet waste from residential areas to the stream. Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

3.2.4 Private Residential Sewage Treatment

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, a distribution box, and a drainage field. Waste flows first to the septic tank, where the solids settle out and are periodically removed by a septic tank pumpout. The

liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the systems drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by dieoff during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems that are more than 50 feet from a stream contribute virtually no fecal coliform to surface waters. Reneau (2000) reported that a very small portion of fecal coliform can survive in the soil system for over 50 days. This number might be higher or lower depending on soil moisture and temperature. An analysis of soil system hydrology for soils typical of the area revealed that lateral movement of 50 feet in 50 days would not be unusual. Based on these analyses, it was estimated that properly functioning septic systems within 50 feet of a stream contribute, on average, 0.001% of fecal coliform production. A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity.

A number of documented failures in the Cedar Run have been established over the years. Several studies have been performed to attempt to quantify the extent of the problem. In Fauquier County, the Catlett Service District has the most serious public health problem caused by failing septic systems. The Fauquier County Health Department has estimated more than 73% of the subsurface disposal systems are currently failing. Individual repair is not possible because of soils that have severe limitations. The Calverton Service District has similar health problems due to unsuitable soils, but is less severe because of lower densities. (Fauquier County, 1994). A number of alternative solutions are currently being discussed and investigated by Fauquier County for implementation with these two service districts.

Upon consultation with the Fauquier County and Prince William County Health Departments a percent failure rate was determined for each modeling segment based upon professional experience and judgment. The 2000 US Census Bureau (USCB)

census block data provides an estimate of the number of Housing Units per segment to calculate the number of systems with the basins, and thus the number of failing systems per model segment (Table 9). Fecal coliform from humans can be transported to streams from failing septic systems. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events.

Table 8. Estimated number of unsewered houses, number of failing septic systems, and pet population in Licking Run watershed

Sub-watershed	Unsewered houses (no.)	Failing septic systems (no.)	Pet population
CER-06	48	1	48
CER-07	218	4	218
CER-08	514	10	514
Total	780	15	780

Table 9. Estimated number of unsewered houses, number of failing septic systems, and pet population in Cedar Run watershed

Sub-watershed	Unsewered houses (no.)	Failing septic systems (no.)	Pet population
CER-01	853	17	853
CER-02	130	3	130
CER-03	385	32	385
CER-04	1639	175	1639
CER-05	3983	80	3983
CER-09	656	13	656
Total	7646	320	7646

3.2.5 Straight Pipes

The Fauquier County and Prince William County Health departments reported no known straight pipes in the Cedar or Licking Run sub-basins. Anecdotal information supplied through the public hearing process indicated that there are several straight pipes in the sub-basins; however no specific locations were provided.

3.3 Livestock Sources

The predominant types of livestock in the Cedar and Licking Run sub-basin are beef and dairy cattle, although all types of livestock identified were considered in modeling the watershed. Animal populations were based on communication with Virginia Cooperative Extension Service (VCE), Natural Resources Conservation Service (NRCS), John Marshall Soil and Water Conservation District (JMSWCD) and Prince William Soil and Water Conservation District (PWSWCD) personnel.

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (e.g. pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Second, grazing livestock deposit manure directly on the land, where it is available for wash-off during a rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams.

One each dairy, beef, and swine producer were identified as collecting and applying a portion of the waste produced on the farm. Time in confinement and estimates of the timing of applications throughout the year were based on data reported by the JMSWCD, PWSWCD, NRCS, VADCR, and VCE (Table 12).

Distribution of Dairy and Beef Cattle in the Cedar Run and Licking Run Watersheds

Based on information provided by the JMSWCD and PWSWCD, the dairy cattle and beef cattle numbers for each sub-watershed in the Licking Run and Cedar Run watersheds are presented in Tables 10 and 11 respectively.

Table 10. Distribution of dairy cattle and beef cattle among Licking Run sub-watersheds

Sub-watershed	Dairy cattle	Beef cattle
CER-06	55	50
CER-07	930	25
CER-08	220	150
Total	1,205	225

Table 11. Distribution of dairy cattle and beef cattle among Cedar Run sub-watersheds

Sub-watershed	Dairy cattle	Beef cattle
CER-01	400	150
CER-02	85	80
CER-03	765	225
CER-04	1885	350
CER-05	330	300
CER-09	1405	600
Total	4870	1705

Beef and dairy cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (e.g., milk cow versus heifer). Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Based on discussions with NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream.

- Cows are confined according to the schedule given in Table 12.
- When the milk cows are not confined or in loafing lots, they spend their remaining time on pasture. All other dairy (dry cows and heifers) and beef cattle are also on pastures when not in confinement or loafing lots.
- Cows on pastures that are contiguous to streams (Tables 13 and 14 for Licking Run and Cedar Run respectively) have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 12). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other reasons.
- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 12. Time spent by cattle in confinement and in the stream.

Month	Time spent in confinement (%)		Time spent in the stream (hours/day) ^a
	Milk cows	Dry cows, heifers, and beef cattle	
January	75%	40%	0.50
February	75%	40%	0.50
March	40%	0%	0.75
April	30%	0%	1.00
May	30%	0%	1.50
June	30%	0%	3.50
July	30%	0%	3.50
August	30%	0%	3.50
September	30%	0%	1.50
October	30%	0%	1.00
November	40%	0%	0.75
December	75%	40%	0.50

^a Time spent in and around the stream by cows that have stream access.

Table 13. Pasture acreages contiguous to stream in the Licking Run watershed.

Sub-watershed	Pasture	
	Acres	% ^a
CER-06	114.6	71%
CER-07	93.6	17%
CER-08	88.8	7%
Total	297	15%

^a Percent of area contiguous to stream to the total pasture area of that type in that sub-watershed.

Table 14. Pasture acreages contiguous to stream in the Cedar Run watershed

Sub-watershed	Pasture	
	Acres	% ^a
CER-01	297.1	14%
CER-02	195.4	43%
CER-03	359.7	15%
CER-04	746.1	19%
CER-05	414.4	11%
CER-09	121.1	10%
Total	2133.8	15%

^a Percent of area contiguous to stream to the total pasture area of that type in that sub-watershed.

The resulting numbers of cattle in each land use type as well as in the stream for all sub-watersheds in Licking Run are given in Tables 15 and 16 for dairy and beef cattle, respectively.

Table 15. Distribution of the dairy cattle population for the Licking Run watershed

Month	Confined	Pasture	Streams^b
January	621.60	406.88	0.52
February	621.60	406.88	0.52
March	240.00	787.53	1.47
April	180.00	846.92	2.08
May	180.00	845.88	3.12
June	180.00	841.71	7.29
July	180.00	841.71	7.29
August	180.00	841.71	7.29
September	180.00	845.88	3.12
October	180.00	846.92	2.08
November	240.00	787.53	1.47
December	621.60	406.88	0.52

^a Includes milk cows, dry cows, and heifers.

^b Number of dairy cattle defecating in stream.

Table 16. Distribution of the beef cattle population for the Licking Run watershed

Month	Confined	Pasture	Streams^a
January	56.70	84.84	0.21
February	58.38	87.35	0.22
March	0.00	149.59	0.56
April	0.00	153.58	0.77
May	0.00	157.37	1.18
June	0.00	159.92	2.83
July	0.00	164.05	2.90
August	0.00	168.18	2.97
September	0.00	104.22	0.78
October	0.00	109.70	0.55
November	0.00	115.07	0.43
December	48.30	72.27	0.18

^a Number of beef cattle defecating in stream.

The resulting numbers of cattle in each land use type as well as in the stream for all sub-watersheds in Cedar Run are given in Tables 17 and 18 for dairy and beef cattle, respectively.

Table 17. Distribution of the dairy cattle population for the Cedar Run watershed

Month	Confined	Pasture	Streams^b
January	2688.25	2586.57	2.06
February	2688.25	2586.57	2.06
March	846.00	4805.82	5.71
April	634.50	5074.40	8.01
May	634.50	5069.35	12.02
June	634.50	5049.16	28.05

Month	Confined	Pasture	Streams^b
July	634.50	5049.16	28.05
August	634.50	5049.16	28.05
September	634.50	5069.35	12.02
October	634.50	5074.40	8.01
November	846.00	4805.82	5.71
December	2688.25	2586.57	2.06

^a Includes milk cows, dry cows, and heifers.

^b Number of dairy cattle defecating in stream.

Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy and beef cattle defecating in the stream. However, only cattle on pastures contiguous to streams have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Part of the fecal coliform deposited in the stream stays suspended while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that suspended fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

Table 18. Distribution of the beef cattle population for the Cedar Run watershed

Month	Confined	Pasture	Streams^a
January	920.70	1379.80	1.25
February	947.98	1420.68	1.29
March	0.00	2434.83	3.32
April	0.00	2501.80	4.55
May	0.00	2567.54	7.01
June	0.00	2625.97	16.78
July	0.00	2693.74	17.21
August	0.00	2761.50	17.65
September	0.00	1700.36	4.64
October	0.00	1787.00	3.25
November	0.00	1872.95	2.55
December	784.30	1175.38	1.07

^a Number of beef cattle defecating in stream.

Direct Manure Deposition on Pastures

Dairy and beef cattle that graze on pastures but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Because the confinement schedule of the cattle changes with season, manure and fecal coliform loading on pasture also change with season.

Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 lb and produces 17 gallons of liquid manure daily (ASAE, 1998). Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure was calculated. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) when applied to land. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture land use categories, respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to only cropland. Because there was more than enough crop area to receive the liquid manure produced in the watershed, no liquid dairy manure was applied to pasture.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay. It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February

through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn, and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye, and surface-applied to cropland under rotational hay. In all months except December and January, liquid manure can be surface-applied. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure is given in Table 19. Dry cows and heifers were assumed to produce only solid manure.

Table 19. Schedule of cattle and poultry waste application in the Licking and Cedar Run watersheds

Month	Liquid manure applied (%) ^a		Solid manure or chicken litter applied (%) ^a	
	Crops	Pasture	Crops	Pasture
January	0	0	0	0
February	7.1	5	6.7	5
March	35.7	25	33.3	25
April	28.6	20	26.7	20
May	7.1	5	6.7	5
June	0	10	0	5
July	0	0	0	5
August	0	5	0	5
September	0	15	0	10
October	7.1	5	13.3	10
November	14.3	10	13.3	10
December	0	0	0	0

^a As percent of annual load applied to each land use type.

Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 20. Solid Manure is last on the priority list for application to land (it falls behind liquid manure and poultry litter). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in

the sub-watershed and their confinement schedules. Solid manure from dry cows, heifers, and beef cattle contain different fecal coliform concentrations (cfu/lb) (Table 21).

Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May, October, and November. Solid manure can be applied to pasture during the whole year, except December and January. The method of application of solid manure to cropland or pasture is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 19.

Table 20. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, and fecal coliform concentration in fresh solid manure in individual cattle type for the Licking Run watershed

Type of cattle	Population	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure ($\times 10^6$ cfu/lb)
Dry cow	275	1,400 ^a	115.0 ^b	176 ^c
Heifer	330	640 ^d	40.7 ^a	226 ^c
Beef	225	1,000 ^e	60.0 ^b	333 ^c

^a Source: ASAE (1998)

^b Source: MWPS (1993)

^c Based on per capita fecal coliform production per day and manure production

^d Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).

^e Based on input from local producers

Table 21. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, and fecal coliform concentration in fresh solid manure in individual cattle type for the Cedar Run watershed

Type of cattle	Population	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure ($\times 10^6$ cfu/lb)
Dry cow	615	1,400 ^a	115.0 ^b	176 ^c
Heifer	2140	640 ^d	40.7 ^a	226 ^c
Beef	1705	1,000 ^e	60.0 ^b	333 ^c

^a Source: ASAE (1998)

^b Source: MWPS (1993)

^c Based on per capita fecal coliform production per day and manure production

^d Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).

^e Based on input from local producers

3.3.1 Chickens

Chicken litter production was estimated from the chicken population after accounting for the time when the houses are not occupied. The chicken population by sub-watershed is given for Licking Run in Table 22 and for Cedar Run in Table 23 and basically consists of small individual backyard coops. There are no large scale poultry operations within the watersheds.

Because chickens are raised entirely in confinement, all litter produced is collected and stored prior to land application. The fecal coliform produced is subject to die-off in storage at a rate of 0.035/day and losses due to incorporation prior to being subject to transport via runoff. Chicken litter is applied at the rate of 3 tons/ac-year first to cropland, and then to pastures at the same rate. Chicken litter receives priority after all liquid manure has been applied (i.e., it is applied before solid cattle manure is considered). The method of chicken litter application to cropland and pastures is assumed to be identical to the method of cattle manure application. The application schedule of poultry litter is given in Table 19. As with liquid and solid manures, chicken litter is not applied to cropland during June through September.

Table 22. Chicken Population in the Licking Run Watershed.

Sub-watershed	Chicken Population
CER-06	3
CER-07	20
CER-08	17

Table 23. Chicken Population in the Cedar Run Watershed.

Sub-watershed	Chicken Population
CER-01	31
CER-02	9
CER-03	31
CER-04	69
CER-05	37
CER-09	3

3.3.2 Sheep, Goats, and Swine

The sheep, goat, and swine populations are presented in Tables 24 and 25 for Licking Run and Cedar Run respectively. It was assumed that the average weight for a sheep, goat and a swine were 140, 60, and 135 lbs, respectively (ASAE, 1998). Sheep and goats are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by sheep and goats was added to the loads applied to pasture as were the swine loads.

Table 24. Swine and Goat Populations in Licking Run by sub-watershed.

Sub-watershed	Sheep	Goat	Swine
CER-06	3	0	1
CER-07	21	2	6
CER-08	18	2	5
Total	42	4	12

Table 25. Swine and Goat Populations in Cedar Run by sub-watershed.

Sub-watershed	Sheep	Goat	Swine
CER-01	33	3	9
CER-02	9	1	2
CER-03	33	3	9
CER-04	59	8	61
CER-05	39	4	11
CER-09	68	60	1
Total	241	79	192

3.3.3 Horses

The distribution of horses among the sub-watersheds is listed in Tables 26 and 27 for Licking Run and Cedar Run respectively. Horses are not usually confined and tend

not to wade or defecate in the streams. Therefore, the fecal coliform produced by horses was added to the loads applied to pasture.

Table 26. Horse Populations among Licking Run by sub-watershed.

Sub-watershed	Horse Population
CER-06	8
CER-07	53
CER-08	45
Total	106

Table 27. Horse Populations among Cedar Run by sub-watershed.

Sub-watershed	Horse Population
CER-01	83
CER-02	23
CER-03	158
CER-04	424
CER-05	98
CER-09	174
Total	960

3.4 Wildlife Sources

In many, if not all TMDL studies the total contribution of fecal coliform from wildlife is really unknown. However, as anyone who has spent any amount of time in the watershed knows, there is a significant natural wildlife population within the Cedar and Licking Run sub-basins. Specific wildlife species are known to exist in the watershed and are suspected of contributing significant quantities of fecal coliform; these include deer, duck, wild turkey, geese, muskrat, raccoon, beaver, and fox. In order to calculate wildlife contributions, individual populations were calculated from the estimated area of suitable habitat for each target species and estimates of population density for each defined suitable habitat.

Suitable habitats for various wildlife species were defined similarly to other estimates prepared for other approved Fecal Coliform TMDLs. Each suitable habitat was

then spatially generated and measured using GIS. Definitions for suitable habitat areas for individual wildlife species are as follows:

- Deer: all forested, cropland, and pasture areas;
- Duck: all forested, cropland, and pasture areas within 400 meters of perennial streams;
- Turkey: all forested areas;
- Goose: all forested, cropland, and pasture areas within 100 meters of surface water impoundments;
- Muskrat: all forested area within 10 meters of perennial streams;
- Raccoon: all forested, cropland, and rural residential areas within 400 meters of perennial streams;
- Beaver: all forested, cropland, and pasture areas within 100 meters of perennial stream.

The percentage of wildlife defecating in the stream each day is based on the habitat and characteristics of the individual wildlife species. Table 28 displays the estimated time that each species spends in the stream and the estimated portion of the animals that are in the stream that are defecating in the stream (VADEQ, 2002).

Table 28. Portion of the day that wildlife spend in the stream and the portion in the stream that are defecating.

Wildlife Species	Portion of the Day Spent In and Around the Stream (%)	Portion of Population in and Around the Stream that are Defecating in the Stream (%)
Deer	5	25
Duck	75	75
Turkey	5	25
Goose	50	50
Muskrat	90	90
Raccoon	5	25
Beaver	100	100

Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, and goose. Population numbers for each species are shown by sub-watershed in Tables 29 and 30 for Licking Run and Cedar Run respectively. Fecal loading from wildlife was estimated for each sub-watershed based upon these population numbers. Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams, considering the habitat

area each occupied. Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams, forest, and cropland.

Table 29. Distribution of wildlife for Licking Run by sub-watershed.

Subwater-shed	Deer	Raccoon	Muskrat	Beaver	Geese	Wild Turkey
CER-06	106	27	121	3	0	6
CER-07	494	131	578	18	356	24
CER-08	624	205	899	27	87	41
Total	1,224	363	1,598	48	443	71

Table 30. Distribution of wildlife for Cedar Run by sub-watershed.

Subwater-shed	Deer	Raccoon	Muskrat	Beaver	Geese	Wild Turkey
CER-01	1,263	377	1,669	58	389	87
CER-02	930	334	1,481	47	451	97
CER-03	909	348	1,592	48	213	53
CER-04	1,601	504	2,283	77	1,234	76
CER-05	1,411	437	1,947	64	2,546	89
CER-09	1,998	574	2,566	80	76	125
Total	8,112	2,574	11,538	374	4,909	527

For each species, a GIS habitat layer was developed based on the habitat descriptions presented above. An example of one of these layers is shown in Figure 11. This layer was overlaid with the land use layer and the resulting area was calculated for each land use in each model segment. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the waste load, fecal coliform densities, and number of animals for each species.

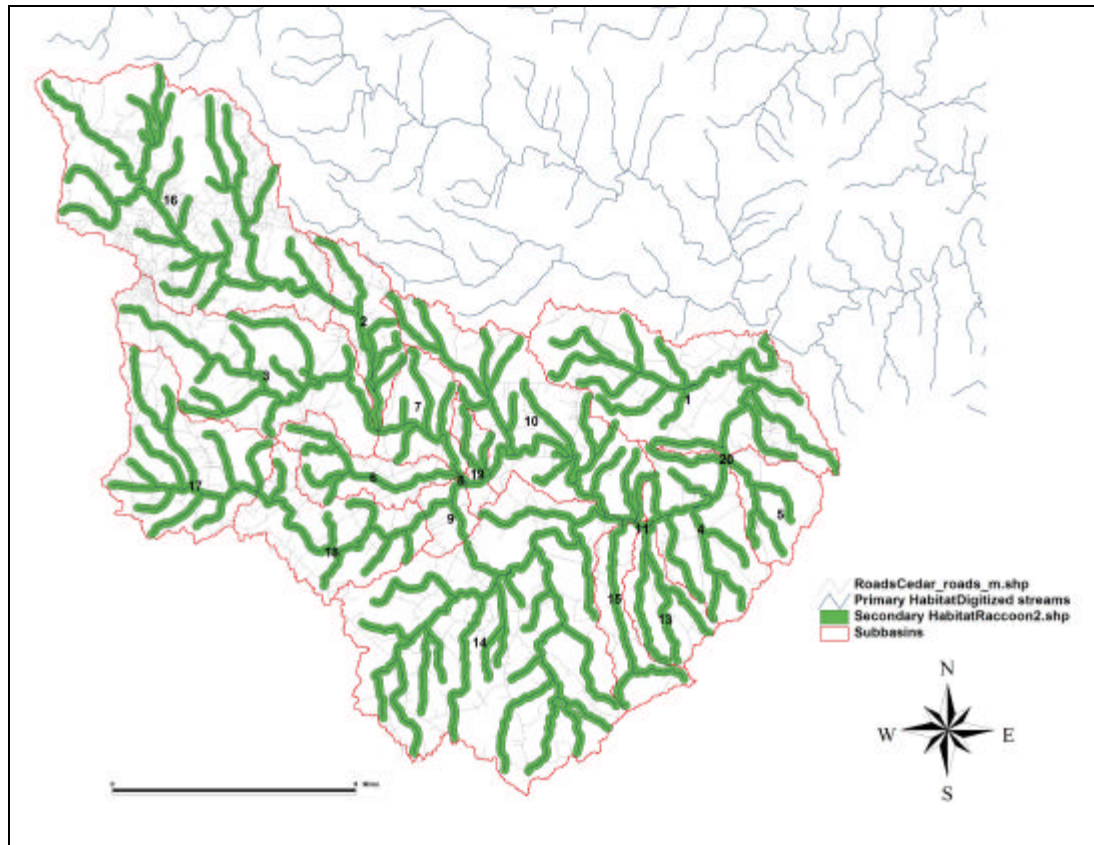


Figure 11. Primary and secondary raccoon habitat.

A synopsis of the fecal coliform sources characterized and accounted for in the Licking Run watershed, along with average fecal coliform production rates, are shown in Table 31. When simulating CER-08, a reduction of 80% was applied to the loadings generated from these animals to account for the reduction in bacteria loadings due to the presence of Germantown Lake at the sub-watershed outlet.

Table 31. Potential fecal coliform sources and daily fecal coliform production by source in Licking Run watershed.

Potential Source	Population in Watershed	Fecal coliform produced ($\times 10^6$ cfu/head-day)
Humans	2,190	1,950 ^a
Dairy cattle		
Milk and dry cows	875	20,200 ^b
Heifers ^c	330	9,200 ^d
Beef cattle	225	20,000
Pets	780	450 ^e
Poultry		
Chicken Broilers	40	136 ^f
Swine	12	12,000 ^f
Goats	4	12,000 ^f
Horses	106	420 ^f
Deer	1,224	350
Raccoons	363	50
Muskrats	1,598	25 ^g
Beavers	48	0.2
Wild Turkeys	71	93 ^f
Geese	443	2,400

^a Source: Geldreich *et al.* (1978)

^b Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)

^c Includes calves

^d Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow

^e Source: Weiskel *et al.* (1996)

^f Source: ASAE (1998)

^g Source: Yagow (2001)

A synopsis of the fecal coliform sources characterized and accounted for in the Cedar Run watershed, along with average fecal coliform production rates are shown in Table 32. In this and all following Cedar Run Tables, the numbers listed represent Cedar Run WITHOUT Licking Run. Licking Run is represented as CER-6, CER-7, and CER-8.

Table 32. Potential fecal coliform sources and daily fecal coliform production by source in Cedar Run watershed

Potential Source	Population in Watershed	Fecal coliform produced ($\times 10^6$ cfu/head-day)
Humans	20,629	1,950 ^a
Dairy cattle		
Milk and dry cows	2,730	20,200 ^b
Heifers ^c	2,140	9,200 ^d
Beef cattle	1,705	20,000
Pets	7,646	450 ^e
Poultry		
Chicken Broilers	243	136 ^f
Swine	192	12,000 ^f
Goats	79	12,000 ^f
Horses	960	420 ^f
Deer	8,112	350
Raccoons	2,574	50
Muskrats	11,538	25 ^g
Beavers	374	0.2
Wild Turkeys	527	93 ^f
Geese	4,909	2,400

^a Source: Geldreich *et al.* (1978)

^b Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)

^c Includes calves

^d Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow

^e Source: Weiskel *et al.* (1996)

^f Source: ASAE (1998)

^g Source: Yagow (2001)

3.4.1 Summary: Contribution from All Sources

Based on the inventory of sources discussed in this chapter, summaries of the contribution by the different nonpoint sources to direct annual fecal coliform loading to the streams are given in Tables 33 and 34 for Licking Run and Cedar Run respectively. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given.

From Tables 33 and 34 it is clear that nonpoint source loadings to the land surface are larger than direct loadings to the streams. Direct loadings make up only 0.5 to 0.6% of the total fecal coliform load, while pasture loads makeup over 90% of the total. This could lead prematurely to the assumption that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors;

such as precipitation amount and pattern, manure application activities (time and method), type of waste (solid versus liquid manure) and proximity to streams; also impact the amount of fecal coliform from upland areas that reaches the streams. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 5.

Table 33. Annual fecal coliform loadings to the stream and the various land use categories in the Licking Run watershed.

Source	Fecal coliform loading (x10¹² cfu/year)	Percent of total loading
Direct loading to streams		
Cattle in stream	36.7	0.5%
Wildlife in stream	7.6	0.1%
Loading to land surfaces		
Cropland	126.7	1.7%
Pasture	7,090	94.7%
Low Density Residential	74.7	1.0%
Forest	149.6	2.0%
Total	7,489.7	

Table 34. Annual fecal coliform loadings to the stream and the various land use categories in the Cedar Run watershed.

Source	Fecal coliform loading (x10¹² cfu/year)	Percent of total loading
Direct loading to streams		
Cattle in stream	159.7	0.3%
Wildlife in stream	100.1	0.2%
Loading to land surfaces		
Cropland	766.7	1.3%
Pasture	53,937	92.1%
Low Density Residential	1,560.3	2.7%
Forest	2,000.8	3.4%
Total	58,532	

4. Calibration and Verification of the Bacteria Model

4.1 The Role of Computer Simulation Modeling in TMDLs

Computer simulation modeling provides the link between the estimated fecal coliform loads generated in the watershed and the in-stream water quality observations that led to the assessment of Cedar and Licking Run as impaired. The goal of the TMDL modeling is to accurately represent the fate and transport of fecal coliform bacteria in the watershed; and then accurately represent the mechanisms and pathways by which the fecal coliforms are generated and transported. Once this is accomplished the model can then be used to determine what load reductions are necessary in the sub-basins to meet water quality standards and to demonstrate that those load allocations permit the sub-basins to meet the standard under a variety of hydrological conditions.

4.1.1 The HSPF Model

The TMDL development requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN, Windows Version (HSPF) (Duda *et al.*, 2001) was used to model fecal coliform transport and fate in the Cedar Run and Licking Run watersheds. The ArcGIS 8.1 GIS program was used to display and analyze landscape information for the development of input for HSPF.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes (Duda *et al.*, 2001). HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from largely impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC

calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the GQUAL sub-module within RCHRES module. Fecal coliform bacteria are simulated as a dissolved pollutant using the general constituent pollutant model (GQUAL) in HSPF.

4.2 Selection of Sub-watersheds

4.2.1 Cedar Run Sub-watersheds

The Cedar Run watershed (VAN-A17R_CER01A02 and VAN-A18R) is a large watershed (126,281 ac) and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into nine sub-watersheds as shown in Figure 12. The impaired section of Cedar Run begins at the confluence of Mill Run with Cedar Run and runs to the confluence of Cedar Run with the Occoquan River. The stream network was delineated based on the blue line stream network from USGS topographic maps with each sub-watershed having at least one stream segment. Because loadings of bacteria are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use.

4.2.2 Licking Run Sub-watersheds

The Licking Run watershed (VAN-A17R_LIL01A00) is a moderately sized watershed (16,381 ac) and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into three sub-watersheds: CER-6, CER-7, and CER-8 shown in Figure 12. The impaired stream section runs from the outlet of Germantown Lake to Licking Run's confluence with Cedar Run. Because loadings of bacteria are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use.



Figure 12. Cedar and Licking Run Sub-Watersheds.

4.3 Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of the watershed. The different types and sources of input data used to develop the TMDLs for the Cedar Run and Licking Run watersheds are discussed below.

4.3.1 Meteorological Data

HSPF requires several types of meteorological input data. The two primary time series for the hydrologic simulation are hourly precipitation data and daily potential evapotranspiration. In addition, the representation of snowmelt requires hourly air temperature, wind speed, solar radiation, and dew point temperature data.

4.3.1.1. Precipitation

Daily precipitation data were available in and around the Cedar and Licking Run sub-basins from four stations in the National Weather Service's Cooperative Station Network (NWSC): The Plains (448396), Warrenton (448888), Dulles Airport (448903), and Reagan National (448903). Past experience with modeling of this watershed has shown The Plains meteorological data to be problematic for use in the Cedar Run watershed due to a number of factors, and as a result this station was not utilized for the analysis. In addition to those NWSC sites, the OWML has had a weather station in operation at their laboratory facilities (OWML Manassas) prior to 1990 and as of 2001 has operated a rain gage station within the Cedar Run sub-basin. Figure 3 shows the location of these stations with respect to the model segments.

The precipitation record from these five stations was used to drive the hydrological component of the HSPF model. Before daily precipitation data can be used in HSPF, missing observations must be filled in and the daily time series of precipitation must be "disaggregated" into an hourly time series. Hourly precipitation data were available from the Reagan National Airport, and sub-hourly data was available from OWML Manassas and OWML Cedar Run (post 2001).

Table 35. Weather Stations used to fill missing daily data and to disaggregate daily data to hourly values.

Station	Missing Data Fill Order	Disaggregation Selection Order
Warrenton	OWML Manassas Dulles	OWML Manassas OWML Cedar Run
OWML Manassas	Reagan National	
OWML Cedar Run	OWML Manassas Reagan National	

4.3.1.2. Other Meteorological Data

Hourly solar radiation, air temperature, dew point, wind speed, and daily potential evapotranspiration were developed for the period 1990-2002 from two primary sources; OWML Manassas and the National Climatic Center's Surface Airways database. Figure

13 presents a comparison between the OWML Manassas and Reagan National hourly temperature recordings. Because Dulles Airport has effectively stopped recording hourly cloud observations, hourly solar radiation for 1998-2002 was calculated from fifteen-minute observations taken at NOAA's Integrated Surface Irradiated Study station in Sterling, VA (NOAA, 2003). To verify the validity of the calculated solar radiation, a plot of the calculated solar radiation from the Dulles cloud data was compared to the measured solar radiation measurements for a two year period of concurrent data collection. The results of that comparison are presented in Figure 14 and show a near perfect correlation of the two methodologies.

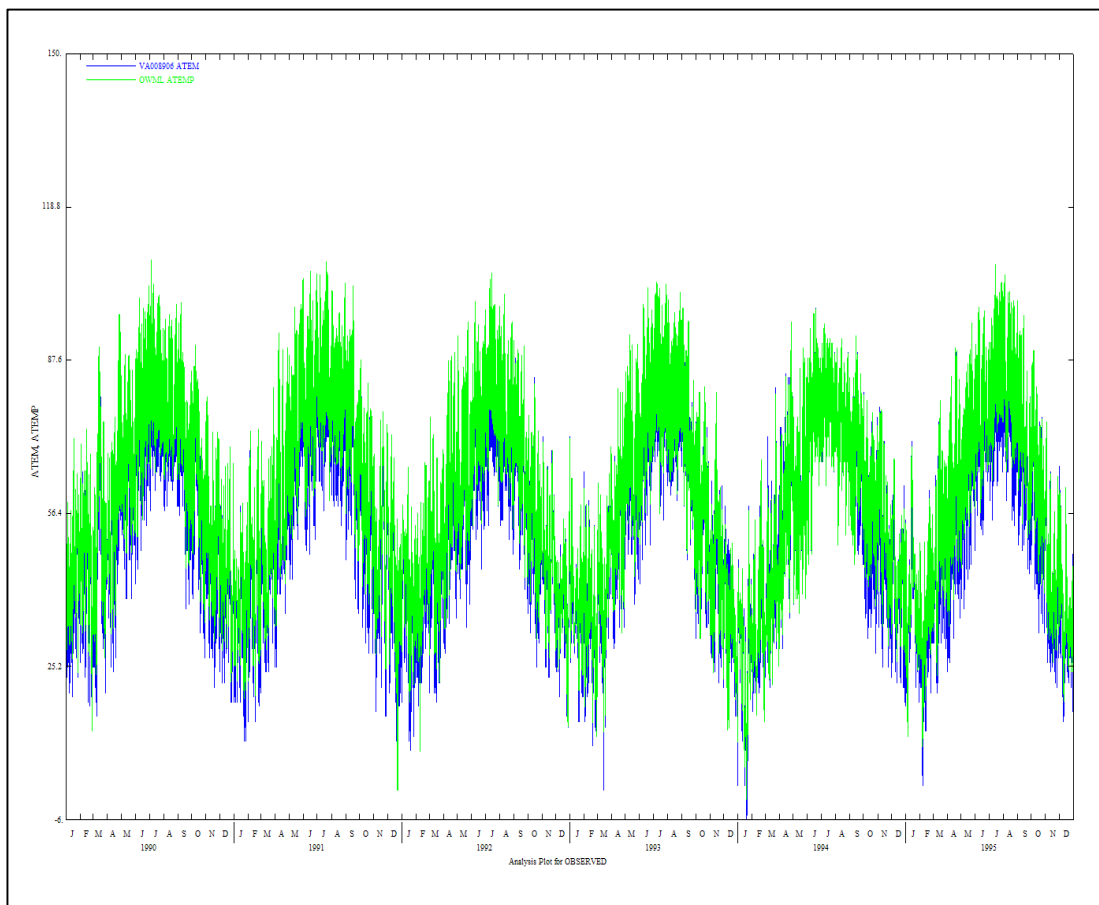


Figure 13. OWML Manassas and Reagan National hourly temperature recording comparison

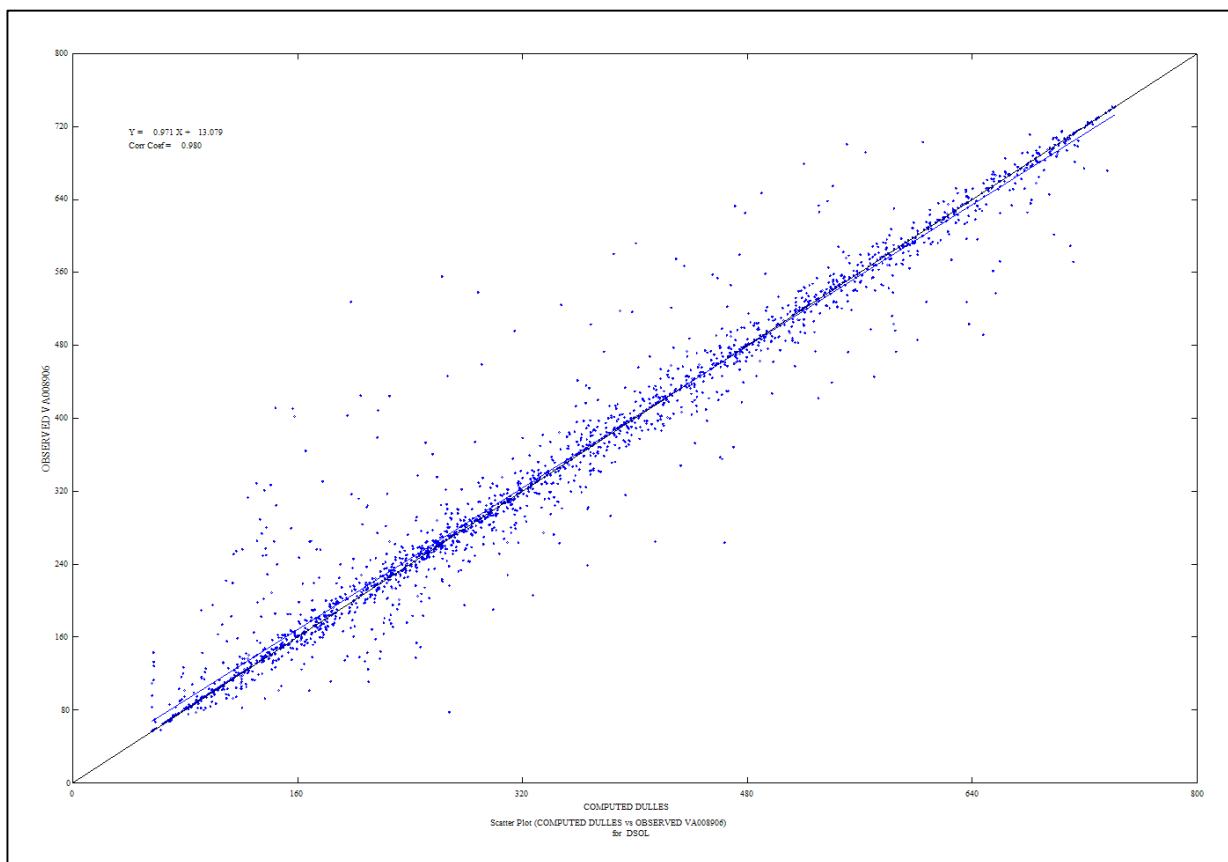


Figure 14. Comparison of calculated solar radiation Dulles cloud data to measured solar radiation.

4.4 Land Use

The NVRC identified 13 land use types in the Cedar Run watershed. The 13 land use types were consolidated into five categories based on similarities in hydrologic features and waste application/production practices (Table 36). These categories were assigned pervious and impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules in HSPF. Land use data were used to select several hydrology and water quality parameter values for the simulations. Land use distribution in the nine sub-watersheds as well as in the entire Cedar Run watershed is presented in Table 37 and graphically in Figure 15. Note that in the Table and figure, the sub-watersheds CER-6, CER-7, and CER-8 comprise the Licking Run watershed.

Table 36. Consolidation of NVPDC Land Use Categories for Cedar Run and Licking Run.

TMDL Land Use Categories	Pervious/Impervious (percentage)^a	NVPDC Land Use Categories
Cropland	Pervious (100%)	Mixed minimum till Mixed conventional till Minimum tillage Conventional tillage-grain
Pasture 2	Pervious (100%)	Livestock
Low Density Residential (LDR)	Pervious (72%) Impervious (28%)	LDR ^b
High Density Residential/Urban Areas (HDR)	Pervious (46%) Impervious (54%)	MDR, Townhouses, Institutional, Industrial, Commercial,
Forest	Pervious (100%)	Forest

^aPercent perviousness/imperviousness information was used in modeling (described in Section 1.4)

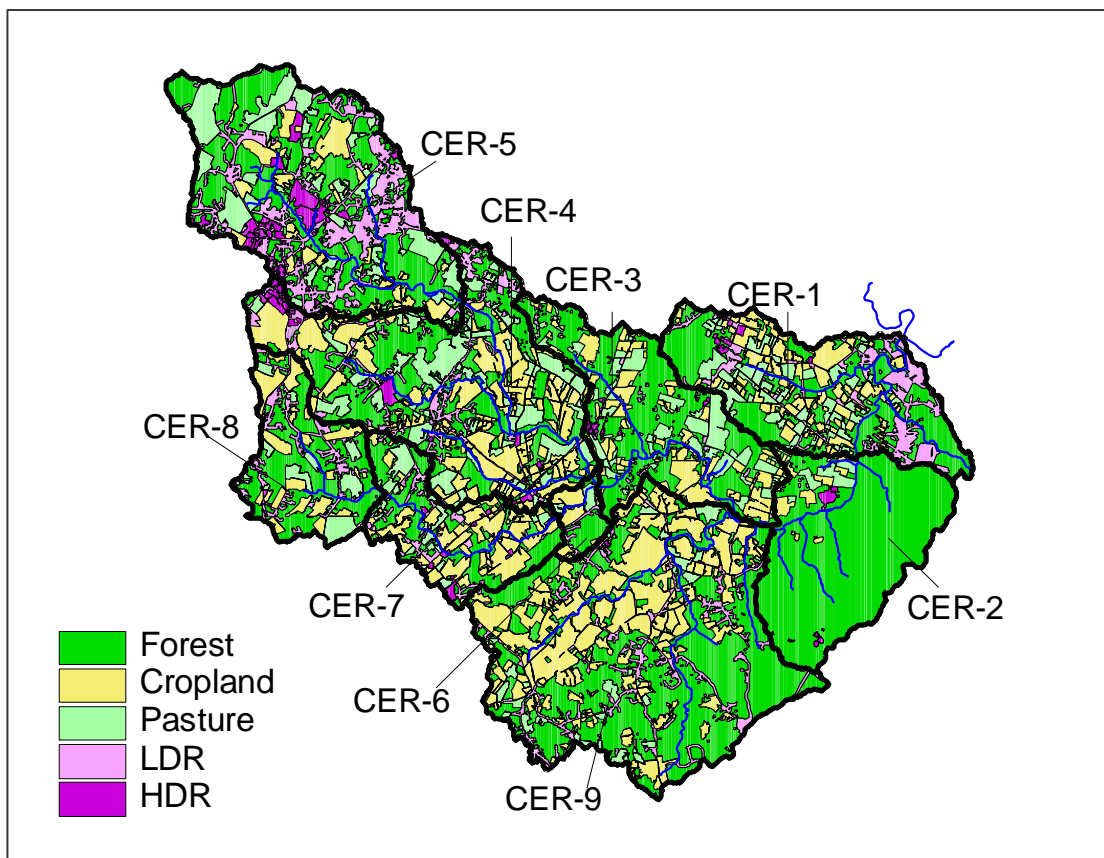


Figure 15. Cedar Run and Licking Run Watersheds Land Use.

Table 37. Land use distribution in the Cedar Run watershed (acres).

Subwatershed Description		Land Use Area (acres)					Sub-watershed Total
		Cropland	Pasture	LDR	HDR	Forest	
CER-1	Cedar Run Outlet	2,875	2,091	2,570	135	8,836	16,507
CER-2	Cedar/Goslin/Lucky Run	923	454	59	152	11,297	12,885
CER-3	Cedar Run/Walnut Branch	2,873	2,341	543	102	6,363	12,222
CER-4	Cedar/Turkey Run	6,680	3,989	2,112	935	7,824	21,540
CER-5	Cedar/Mill Run	2,162	3,835	4,187	1,763	9,060	21,007
CER-6	Licking Run Outlet	508	162	158	0	583	1,411
CER-7	Licking Run below Germantown Lake	2,648	564	711	142	2,503	6,568
CER-8	Licking Run above Germantown Lake	1,724	1,227	1,221	41	4,189	8,402
CER-9	Elk/Town Run	9,360	1,227	2,391	24	12,737	25,739
Total Area by Land Use		29,753	15,890	13,952	3,294	63,392	126,281

4.5 Accounting for Pollutant Sources

4.5.1 Overview

There were 15 VADEQ permitted bacteria point sources in the Cedar Run and Licking Run watersheds. Three of these were larger VPDES-permitted dischargers, and the remaining twelve permitted sources were general permits for facilities/residences discharging at or less than 1,000 gallons per day. In addition, two MS4 permits were located in the Cedar Run watershed, VA0088595 and VAR040100. While the MS4 permits are regulated similarly to point source discharges, water quality discharging from the MS4s is nearly exclusively dictated by nonpoint source runoff (along with an unknown, but presumed small, amount of illicit connections). Fecal coliform loads modeled from impervious areas within the MS4 areas are included in the wasteload allocation (WLA) component of the TMDL, in compliance with 40 CFR §130.2(h). Fecal coliform loads related to stormwater runoff from areas covered by MS4 permits were modeled with HSPF as contributions from impervious land use categories. Because the Schools' permit covers part of the area already covered by the County permit, a single allocation was developed and assigned jointly to the two permits.

Bacteria loads that are directly deposited by cattle and wildlife in streams were treated as direct nonpoint sources in the model. Bacteria that were land-applied or deposited on land were treated as nonpoint source loadings; all or part of that load may be transported to the stream as a result of surface runoff during rainfall events. Direct nonpoint source loading was applied to the stream reach in each sub-watershed as appropriate. The point sources permitted to discharge bacteria in the watershed were incorporated into the simulations at the stream locations designated in the permit.

The nonpoint source loading was applied in the form of fecal coliform counts to each land use category in a sub-watershed on a monthly basis. Fecal coliform die-off was simulated while manure was being stored, while it was on the land, and while it was transported in streams. Both direct and indirect nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams.

The Biological Systems Engineering (BSE) Department at Virginia Tech developed a spreadsheet program that was used to generate the nonpoint source fecal coliform inputs to the HSPF model. This spreadsheet program takes inputs of animal numbers, land use, and management practices by sub-watershed and outputs hourly direct deposition to streams and monthly loads to each land use type. The BSE program was customized to allow direct deposition in the stream by dairy cows, ducks, and geese to occur only during daylight hours. The spreadsheet program calculates the manure produced in confinement by each animal type (dairy cows, beef cattle, and poultry) and distributes this manure to available lands (crops and pasture) within each sub-watershed. If a sub-watershed does not have sufficient land to apply all the manure its animals generate, the excess manure is distributed equally to other sub-watersheds that have land that has not yet received manure. In Cedar Run and Licking Run, however, there was sufficient land available in each sub-watershed such that all manure generated within a sub-watershed could be applied in the same sub-watershed.

4.5.2 Modeling fecal coliform die-off

Fecal coliform die-off was modeled using first order die-off of the form:

$$C_t = C_0 10^{-Kt} \quad [4.1]$$

where: C_t = concentration or load at time t ,
 C_0 = starting concentration or load,
 K = decay rate (day^{-1}),
and t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the Cedar Run and Licking Run watersheds (Table 38).

Table 38. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources.

Waste type	Storage/application	Decay rate (day ⁻¹)	Reference
Dairy manure	Pile (not covered)	0.066	Jones (1971) ^a
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Coles (1973) ^a
Poultry litter	Soil surface	0.035	Giddens <i>et al.</i> (1973)
		0.342	Crane <i>et al.</i> (1980)

^a Cited in Crane and Moore (1986)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Because the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoons (0.375 day⁻¹) was used.
- Solid cattle manure: Based on the range of decay rates (0.028-0.066 day⁻¹) reported for solid dairy manure, a decay rate of 0.05 day⁻¹ was used assuming that a majority of manure piles are not covered.
- Poultry waste in pile/house: Because no decay rates were found for poultry waste in storage, a decay rate of 0.035 day⁻¹ was used based on the lower decay rate reported for poultry litter applied to the soil surface. The lower value was used instead of the higher value of 0.342 day⁻¹ (Table 38) because fecal coliform die-off in storage was assumed to be lower, given the absence of UV radiation and predation by soil microbes.

Depending on the duration of storage, type of storage, type of manure, and die-off factor, the fraction of fecal coliform surviving in the manure at the end of storage is calculated. While calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. The amount of fecal coliform available for application to land per year is estimated by multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure). Monthly fecal coliform application to land is estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied

to land during that month. A decay rate of 0.045 day^{-1} was assumed for fecal coliform on the land surface. The decay rate of 0.045 day^{-1} is represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of 1.15 day^{-1} was used.

4.5.3 Modeling Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land and, hence, required surface runoff events for transport to streams. Fecal coliform loading by land use for all sources in each sub-watershed is presented in an Appendix F. The existing condition fecal coliform loads are based on best estimates of existing wildlife, livestock, and human populations and fecal coliform production rates. Fecal coliform in stored waste was adjusted for die-off prior to the time of land application when calculating loadings to cropland and pasture. For a given period of storage, the total amount of fecal coliform present in the stored manure was adjusted for die-off on a daily basis. Fecal coliform loadings to each sub-watershed in the Cedar Run and Licking Run watersheds are presented in Appendix E. The sources of fecal coliform to different land use categories and how the model handled them are briefly discussed below.

1. Cropland: Liquid dairy manure and solid manure are applied to cropland. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land-application. Wildlife contributions were also added to the cropland areas. For modeling, monthly fecal coliform loading assigned to cropland was distributed over the entire cropland acreage within a sub-watershed. Thus, loading rate varied by month and sub-watershed.
2. Pasture: Pasture: Pastures in the Licking and Cedar Run watersheds receive direct deposition of manure from livestock and wildlife. For modeling, monthly fecal coliform loading assigned to pasture was distributed over the entire pasture acreage within a sub-watershed
3. Low Density Residential and Farmstead: Fecal coliform loading on rural residential and Farmstead land use came from failing septic systems, wildlife and

waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a sub-watershed were combined and assumed to be uniformly applied to the low density residential pervious land use areas. Impervious areas (Table 36) received constant loads of 1.0×10^7 cfu/acre/day.

4. Urban Areas: Fecal coliform loading to the urban areas came from pets and wildlife in these areas; the impervious load was assumed to be a constant 1.0×10^7 cfu/acre/day (USEPA, 2000).
5. Forest: Wildlife not defecating in streams, cropland, and pastures provided fecal coliform loading to the forested land use. Fecal coliform from wildlife in forests was applied uniformly over the forest areas.

4.5.4 Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources included cattle in streams and wildlife in streams. Also, contributions of fecal coliform from interflow and groundwater were modeled as having a constant concentration of 30 cfu/100mL for interflow and 20 cfu/100mL for groundwater. Loads from direct nonpoint sources in each sub-watershed are described in detail in Appendix E.

4.6 Model Calibration and Validation

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. Validation ensures that the calibrated parameters are appropriate for time periods other than the calibration period. In this section, the procedures followed for calibrating the hydrology and water quality components of the HSPF model are discussed. The calibration and validation results of the hydrology component and the calibration results of the water quality component are presented.

The hydrology of the Cedar Run watershed was calibrated using streamflow data from station ST25 monitored by the OWML. A Licking Run hydrologic calibration could not be performed, as no streamflow data were available. Because Licking Run is a part of Cedar Run, the calibrated hydrology parameters for Cedar Run were also used for

Licking Run. Both watersheds had available data for water quality calibration and so were considered separately for the water quality calibration.

4.6.1 Cedar Run

4.6.1.a. Hydrology

The hydrologic calibration period was June 1, 1990 to December 31, 1994. The hydrologic validation period was from January 1, 1995 to June 30, 1998. The output from the HSPF model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended range.

The HSPEXP decision support system developed by USGS was used to calibrate the hydrologic portion of HSPF for Cedar Run. The default HSPEXP criteria for evaluating the accuracy of the flow simulation were used in the calibration for Cedar Run. These criteria are listed in Table 39. After calibration, with the exception of the lowest flows and seasonal volumes criteria, all criteria listed in Table 39 were met. The lowest flows and seasonal volume criteria were relaxed due to difficulty in modeling known but undocumented irrigation practices.

Table 39. Default criteria for HSPEXP.

Variable	Percent Error
Total Volume	10%
50 % Lowest Flows	10%
10 % Highest Flows	15%
Storm Peaks	15%
Seasonal Volume Error	10%
Summer Storm Volume Error	15%

The simulated flow for both the calibration and validation matched the observed flow well, as shown in Figure 16 and Figure 17. The agreement with observed flows is further illustrated in Figure 18 and Figure 19 for a representative year and Figure 20 and Figure 21 for a representative storm.

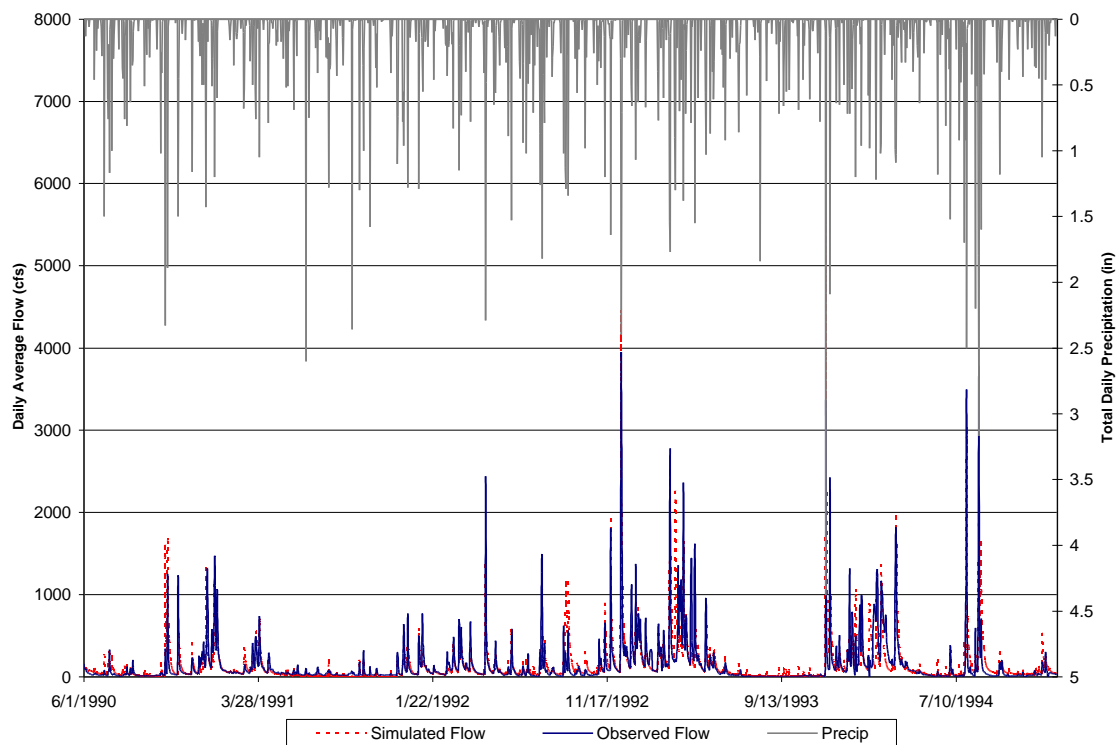


Figure 16. Observed and simulated flows and precipitation for Cedar Run for the calibration period.

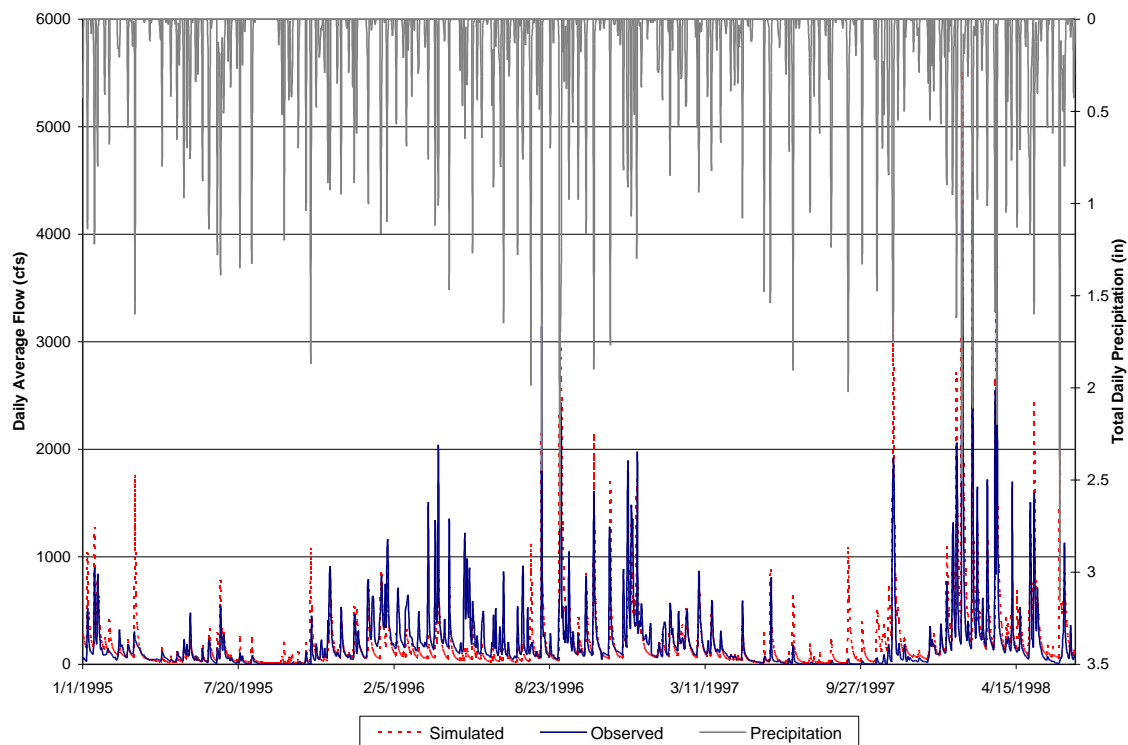


Figure 17. Observed and simulated flows and precipitation for Cedar Run during the validation period.

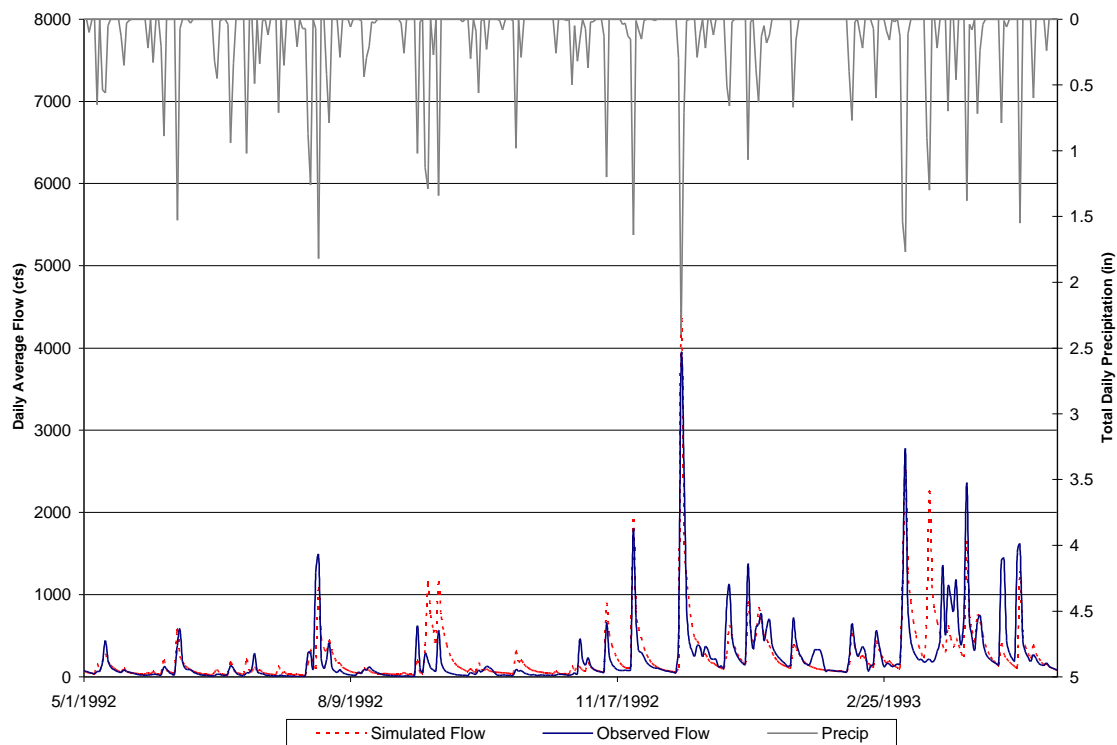


Figure 18. Observed and simulated flows and precipitation for a representative year in the calibration period for Cedar Run.

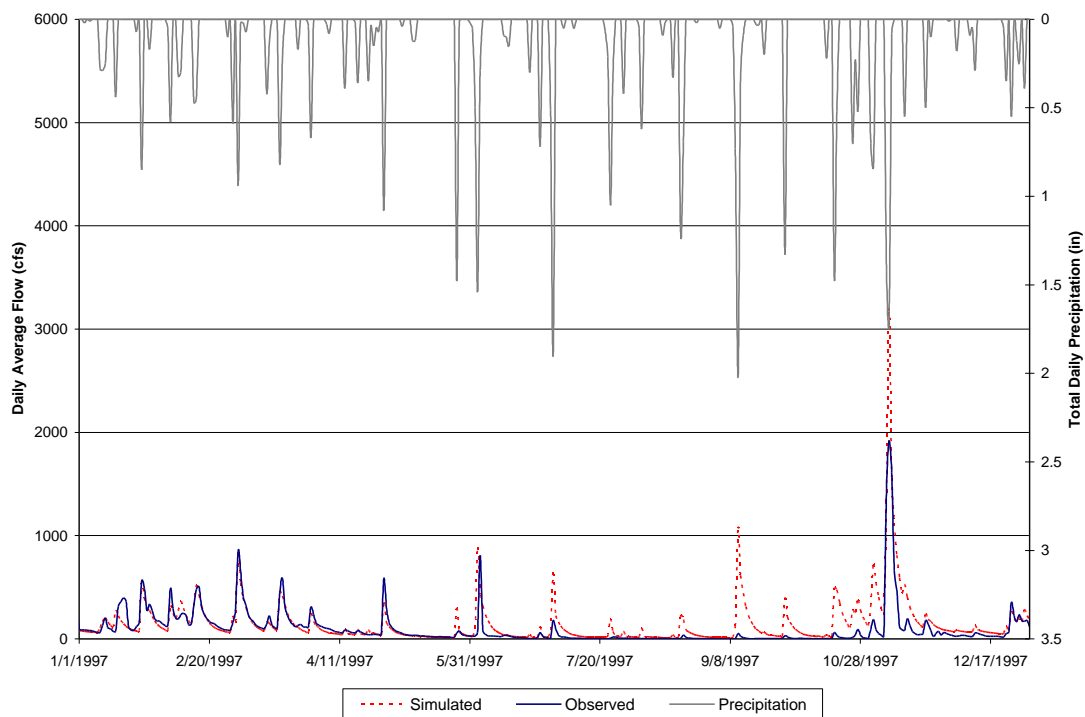
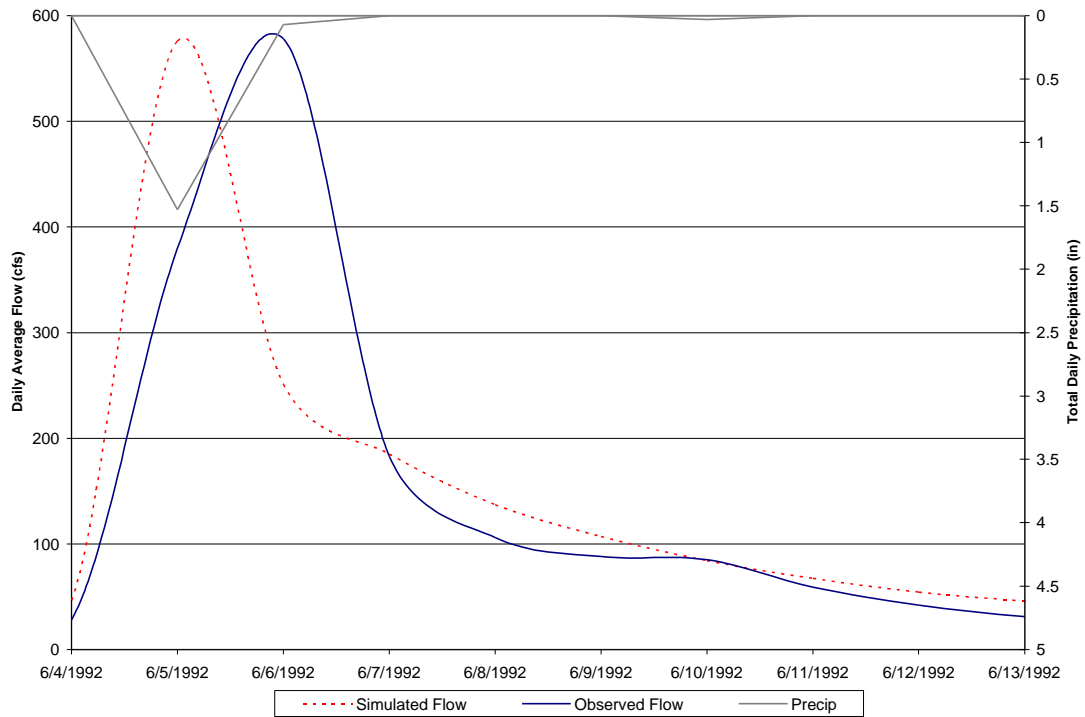


Figure 19. Observed and simulated flows and precipitation for Cedar Run during a representative year in the validation period.



Fig

Figure 20. Observed and simulated flows and precipitation for Cedar Run for a representative Storm in the calibration period.

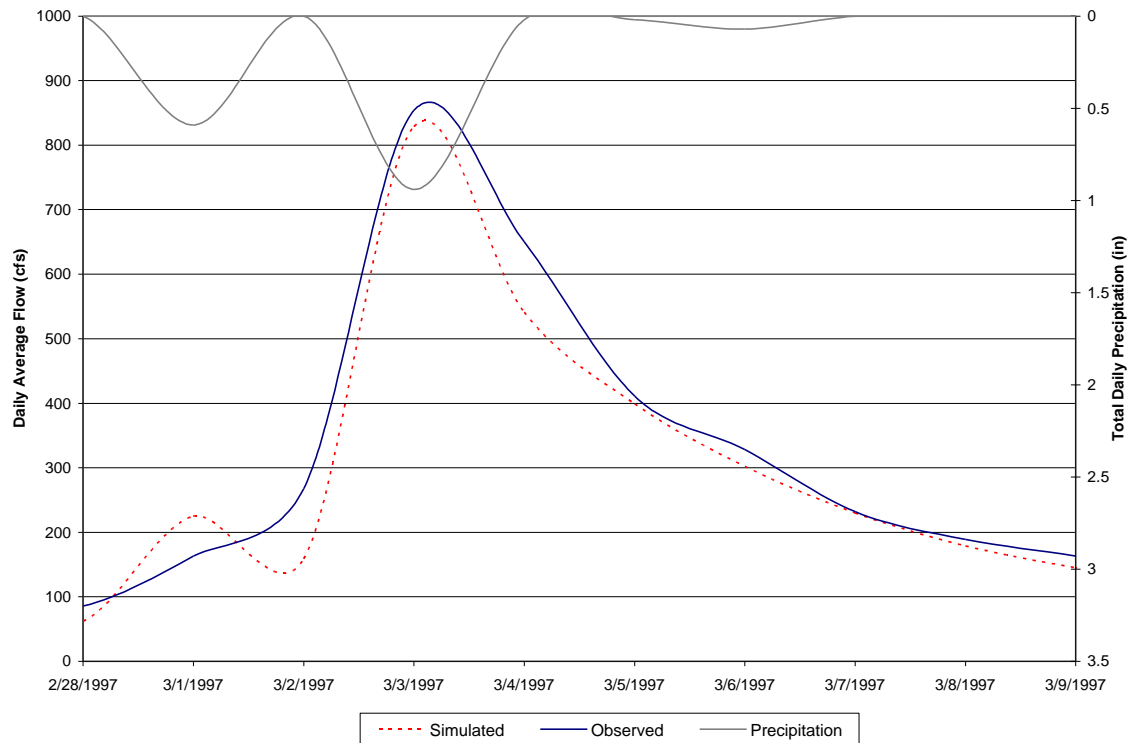


Figure 21. Observed and simulated flows, and precipitation for Cedar Run for a representative storm in the validation period.

The agreement between the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves (Figure 22 and Figure 23).

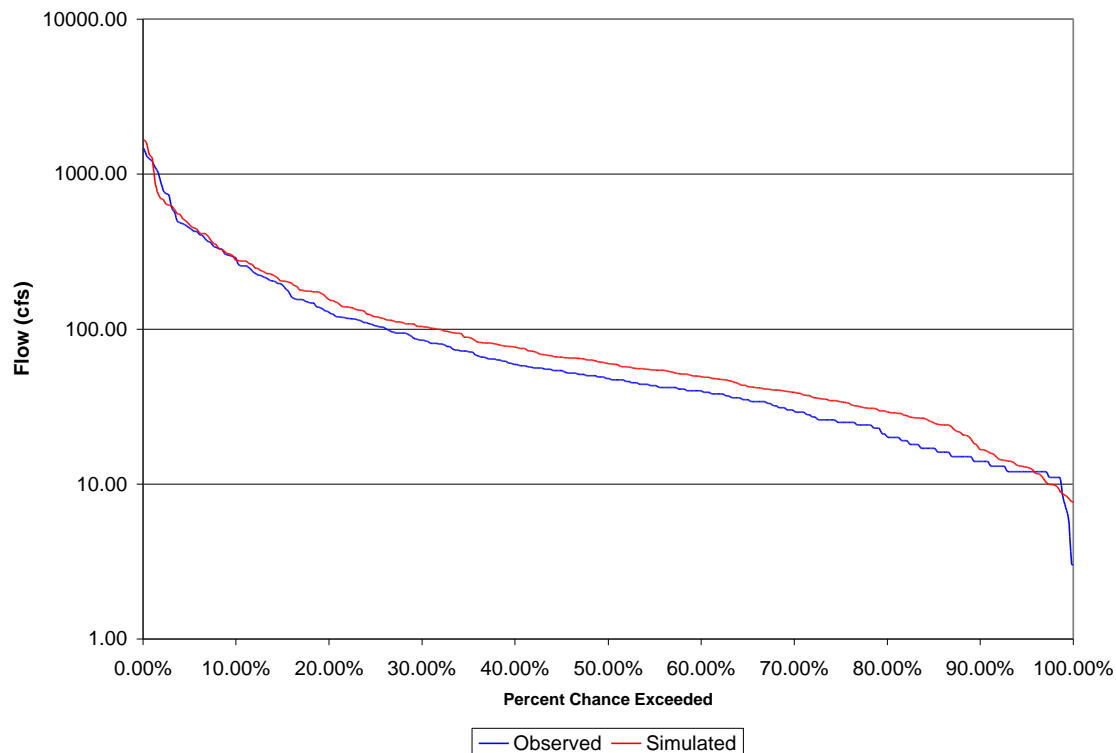


Figure 22. Cumulative frequency curves for the calibration period for Cedar Run.

As previously mentioned, the expert system HSPEXP was used to assist with calibrating and validating the Cedar Run hydrologic model. Selected diagnostic output from the program is listed in Table 40 and Table 41. All values were within the desired criteria except for the lowest 50% of flows and the seasonal volume criteria. Examining the flow record for Cedar Run revealed that during the summer the average streamflow values decrease by two orders of magnitude. This decrease is due to known irrigation withdrawals; however, these withdrawals could not be modeled using HSPF due to lack of quantification of said withdrawals. Despite the lack of irrigation withdrawal modeling, the calibration still agrees reasonably well with the available streamflow data, as illustrated by the calibration and validation graphs in Figure 16, Figure 17, Figure 18, and Figure 19.

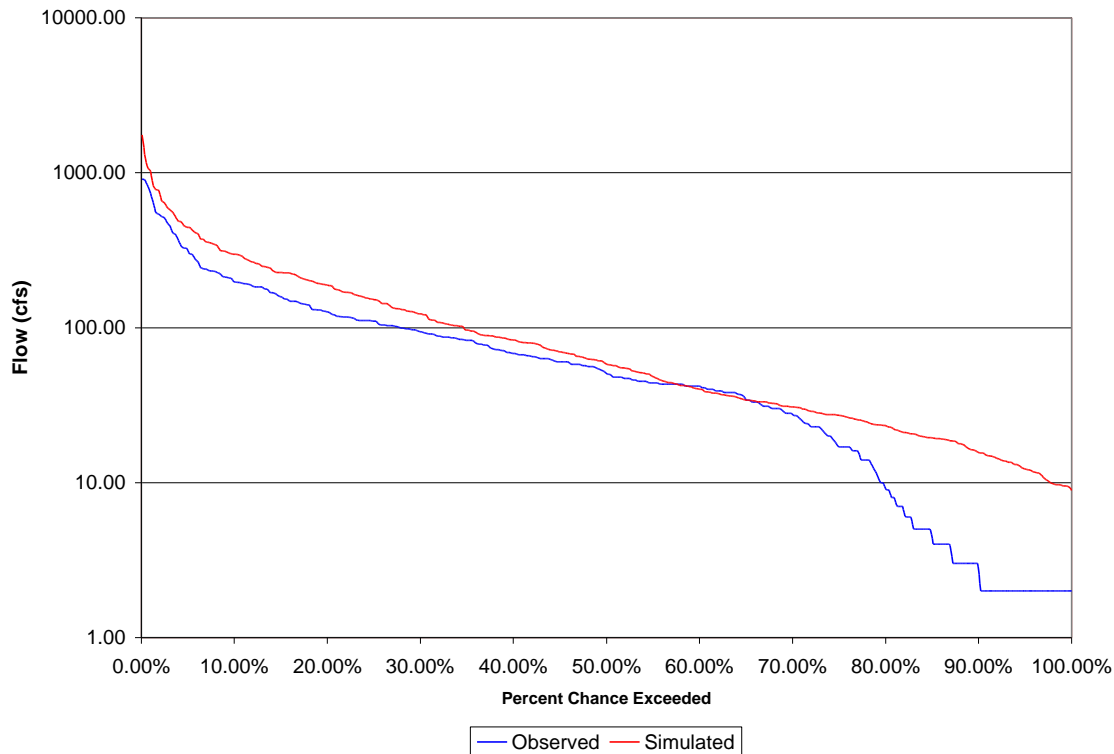


Figure 23. Cumulative frequency curves for the validation period for Cedar Run.

The total winter runoff and total summer runoff errors are considered in the HSPEXP term ‘seasonal volume error’ (see Table 39). The errors for seasonal volume error were 30.6% for the calibration period and 24% for the validation period. While neither of these values is within the desired range of $\pm 10\%$, this is not unexpected because seasonal volume takes into account the very low flows of the summer, which could not be modeled due to known irrigation withdrawals, as explained previously.

Table 40. Summary statistics for the calibration period for Cedar Run.

	Simulated	Observed	Error (%)	Criterion
Total Runoff	55.420	53.122	4.3	10%
Average Annual Total Runoff	12.077	11.576	4.3	10%
Total of Highest 10% of flows	29.30	30.420	-3.7	15%
Total of Lowest 50% of flows	4.740	3.875	22.3	15%
Total Winter Runoff	18.910	20.826	-3.3	na
Total Summer Runoff	9.040	7.444	21.4	na
Coefficient of Determination, r^2	0.54			

na = not applicable; these are not criteria directly considered by HSPEXP

Flow partitioning for Cedar Run hydrologic model calibration and validation is shown in Table 42. When the observed flow data were evaluated using HYSEP (Sloto, and. Crouse, 1996), the baseflow index for both the calibration and validation periods was 0.40. Due to the aforementioned irrigation withdrawals and the presence of lakes in the watershed, the simulated baseflow indices shown in Table 42 adequately match the observed value.

Table 41. Summary statistics for the validation period for Cedar Run.

	Simulated	Observed	Error (%)	Criterion
Total Runoff	62.650	57.849	8.3	10%
Average Annual Total Runoff	17.910	16.538	8.3	10%
Total of Highest 10% of flows	30.520	28.404	7.4	15%
Total of Lowest 50% of flows	6.820	5.653	20.6	15%
Total Winter Runoff	10.420	11.754	-11.3	na
Total Summer Runoff	8.120	6.344	28.0	na
Coefficient of Determination, r^2	0.53			

na = not applicable; these were not criteria directly considered by HSPEXP

Table 42. Partitioning for the calibration and validation periods for Cedar Run.

Average Annual Flow	Calibration	Validation
Total Annual Runoff (in)	55.420	62.650
Surface Runoff (in)	12.077 (21.79%)	17.910 (28.59%)
Interflow (in)	6.311 (11.39%)	9.605 (15.33%)
Baseflow (in)	37.032 (66.82%)	35.135 (56.08%)
Baseflow Index	0.67	0.56

A list of final calibration parameters for both the hydrology and water quality simulations can be found at the end of the next section (Tables 44 and 45).

4.6.1.b. Water Quality calibration

Direct Deposition of Manure at Very Low Flows

The direct deposition of manure in streams by livestock was modified based on stream depth during conditions of low flow. Fecal coliform inputs by livestock in streams are typically simulated without regard to stream depth. Under extreme low flow conditions, one animal defecating once in a stream reach can result in a violations of the instantaneous water quality standard; however, under such extreme low flows, it is not likely for animals to wade in or drink from the stream. Therefore, modeled direct deposition of manure by livestock at extreme low flow conditions can cause unrealistically high numbers of violations, make calibration difficult, and adversely affect the quality of the final calibration.

In order to more accurately model the water quality conditions in Cedar Run, a stage (stream depth) of 3 inches was used as a cutoff for cattle direct deposition of manure. Due to modeling constraints, for Cedar Run, the direct deposition values were filtered based on the flows corresponding to a 3-inch depth listed in the F-Tables instead of actual depth (stage). Because the F-Tables are specific to subwatersheds, direct deposition in each subwatershed was filtered separately. When the streamflow in a subwatershed was less than the flow corresponding to a 3-inch depth, direct deposition by cattle was set to zero; at streamflow values greater than the flow corresponding to a 3-inch depth, direct deposition was unchanged. This 3-inch cutoff value has been used successfully and its validity analyzed in previously approved TMDLs in Virginia.

Using a 3-inch stage cutoff for manure deposition by cattle reduces the possibility of unrealistic low-flow violations, resulting in a more accurate description of the fecal coliform concentration in the stream. Consequently, the 3-inch stage cutoff method was used for the calibration and allocation scenarios for the Cedar Run watershed.

Cedar Run Calibration using 3-inch Stage Direct Deposition Cutoff

The water quality calibration was performed at an hourly time step using the HSPF model. The water quality calibration period was June 1, 1990 through December 31, 1994. Observed water quality data were obtained from the DEQ station 1ACER006.00 on

Cedar Run. Output from the HSPF model was generated as an hourly timeseries and daily average timeseries of fecal coliform concentration. *E. coli* concentrations were determined using the following translator equation supplied by DEQ:

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \quad (1)$$

The *E. coli* translator was implemented in the HSPF simulation using the GENER block. The geometric mean was calculated on a monthly basis. Table 43 contains the simulated percent contributions from the major source categories to the instream load during the calibration period.

Table 43. Simulated percent contributions from major source categories for Cedar Run during the calibration period.

Scenario	Livestock DD	Livestock Land	Wildlife DD	Wildlife Land	Septic Systems	Cats/ Dogs	Impervious	Interflow and Groundwater
Total period	6.4%	84.8%	3.41%	2.08%	0.52%	2.50%	0.12%	0.15%

DD = direct deposit

In addition to correlating well with the BST results, the simulated fecal coliform concentrations agree well with the observed fecal coliform concentrations. Figure 24 shows the daily average simulated fecal coliform concentrations and the observed data from the DEQ sampling station. At the DEQ sampling station the maximum observed concentration was a capped value of 16,000 cfu/100 mL and the overall maximum simulated concentration at this point was 27,600 cfu/100 mL.

The geometric mean for the observed data at the DEQ station for the calibration period is 317 cfu/100 mL and the geometric mean for the simulated data for the same period at this station is 597 cfu/100 mL. The violations rate of the instantaneous interim fecal coliform water quality standard of 400 cfu/100 mL is 38% for the observed DEQ data and 55% for the simulated water quality data. The final parameters used in the calibration and validation simulations are listed in Tables 44 and 45.

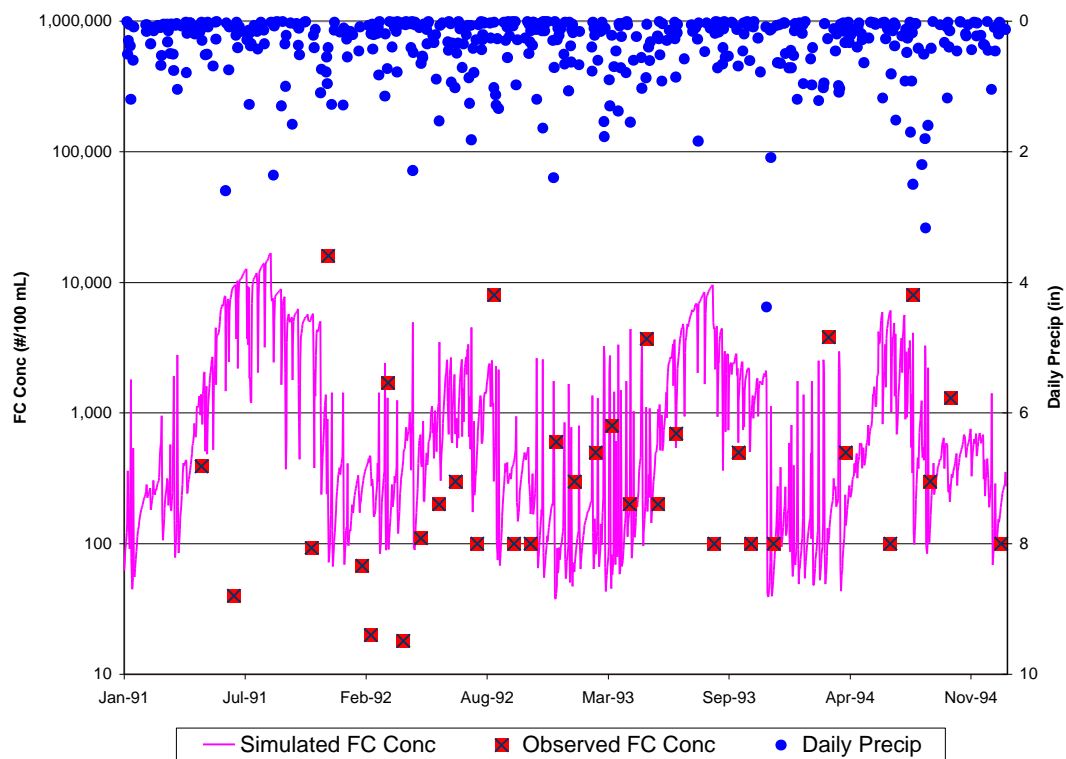


Figure 24. Observed Concentrations and Simulated Fecal Coliform Concentrations for the Water Quality Calibration Period.

Table 44. Final calibrated parameters for Cedar Run and Licking Run.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF...	Appendix Table (if applicable) ^c
PERLND					
PWAT-PARM2					
FOREST	Fraction forest cover	none	1.0 forest, 0.0 other	Forest cover	
LZSN	Lower zone nominal soil moisture storage	inches	10 forest, 8.5 other	Soil properties	
INFILT	Index to infiltration capacity	in/hr	0.07 forest, 0.03 other	Soil and cover conditions	
LSUR	Length of overland flow	feet	275-377 ^a	Topography	1
SLSUR	Slope of overland flowplane	none	0.02-0.107 ^a	Topography	1
KVARY	Groundwater recession variable	1/in	0.0	Calibrate	
AGWRC	Base groundwater recession	none	0.98 forest, 0.96 other	Calibrate	
PWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
INFEXP	Exponent in infiltration equation	none	2	Soil properties	
INFILD	Ratio of max/mean infiltration capacities	none	2	Soil properties	
DEEPFR	Fraction of GW inflow to deep recharge	none	0.5	Geology	
BASETP	Fraction of remaining ET from baseflow	none	0.04 forest, 0.01 other	Riparian vegetation	
AGWETP	Fraction of remaining ET from active GW	none	0	Marsh/wetlands ET	
PWAT-PARM4					
CEPSC	Interception storage capacity	inches	monthly ^b	Vegetation	2
UZSN	Upper zone nominal soil moisture storage	inches	monthly ^b	Soil properties	3
NSUR	Mannings' n (roughness)	none	0.15-0.3 ^a	Land use, surface condition	1
INTFW	Interflow/surface runoff partition parameter	none	4.0	Soils, topography, land use	
IRC	Interflow recession parameter	none	0.7	Soils, topography, land use	
LZETP	Lower zone ET parameter	none	monthly ^b	Vegetation	4

^aVaries with land use

^bVaries by month and with land use

^cTables located in Appendix E

Table 45. Final calibrated parameters for Cedar Run and Licking Run.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF...	Appendix Table (if applicable)
QUAL-INPUT					
SQO	Initial storage of constituent	no./ac	0-3x11 ^{10a}	Land use	5
POTFW	Washoff potency factor	no./ton	0		
POTFS	Scour potency factor	no./ton	0		
ACQOP	Rate of accumulation of constituent	no./day	monthly ^b	Land use	6
SQOLIM	Maximum accumulation of constituent	#	9 x ACQOP ^b	Land use	7
WSQOP	Wash-off rate	in/hr	2.5	Land use	
IOQC	Constituent conc. in interflow	no./ft3	8496	Land use	
PERLND					
AOQC	Constituent conc. in active groundwater	no./ft3	5664	Land use	
IMPLND					
IWAT-PARM2					
LSUR	Length of overland flow	feet	341 LDR, 353HDR	Topography	
SLSUR	Slope of overland flowplane	none	0.04 LDR, 0.05 HDR	Topography	
NSUR	Mannings' n (roughness)	none	0.1	Land use, surface condition	
RETSC	Retention/interception storage capacity	inches	0.1	Land use, surface condition	
IWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
IQUAL					
SQO	Initial storage of constituent	#/ac	1x10 ⁷		
POTFW	Washoff potency factor	#/ton	0		
ACQOP	Rate of accumulation of constituent	#/day	1x10 ⁷	Land use	
SQOLIM	Maximum accumulation of constituent	#	3x10 ⁷	Land use	
WSQOP	Wash-off rate	in/hr	1.5	Land use	
RCHRES					
HYDR-PARM2					
KS	Weighting factor for hydraulic routing		0.5		
GQUAL					
FSTDEC	First order decay rate of the constituent	1/day	1.15		
THFST	Temperature correction coeff. for FSTDEC		1.05		

^aVaries with land use

^bVaries by month and with land use

^cTables located in Appendix E

4.6.2 Licking Run

4.6.2.a. Water Quality Calibration

Licking Run Calibration using 3-inch Stage Direct Deposition Cutoff

To improve the accuracy of the water quality modeling, a 3-inch cutoff based on flow rate for a 3-inch stage was used to filter direct deposition of manure by cattle as described in Section 1.6.1.b for Cedar Run.

The water quality calibration was performed at an hourly time step using the HSPF model. Observed water quality data was obtained from the DEQ station 1aLIL001.43 on Licking Run. The water quality calibration period was June 1, 1990 through December 31, 1994. Output from the HSPF model was generated as an hourly timeseries of fecal coliform concentration. *E. coli* concentrations were determined using the following translator equation supplied by DEQ:

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \quad (2)$$

The *E. coli* translator was implemented in the HSPF simulation using the GENER block. The geometric mean was calculated on a monthly basis. The final calibration parameters are shown in Tables 44 and 45. Table 46 contains the simulated percent contributions from the major source categories to the instream load during the calibration period.

Table 46. Simulated percent contributions from major source categories for Licking Run during the calibration period.

Scenario	Livestock DD	Livestock Land	Wildlife DD	Wildlife Land	Septic Systems	Cats/ Dogs	Impervious	Interflow and Groundwater
Total period	10.19%	84.31%	1.97%	1.06%	0.18%	0.93%	0.14%	1.21%

DD = direct deposit

The simulated fecal coliform concentrations agree well with the observed fecal coliform concentrations. Figure 25 shows the daily average simulated fecal coliform concentrations and the observed data from the DEQ water quality station. At the DEQ

sampling station the maximum observed concentration was a capped value of 8,000 cfu/100 mL and the overall maximum simulated concentration at this point was 27,500 cfu/100 mL.

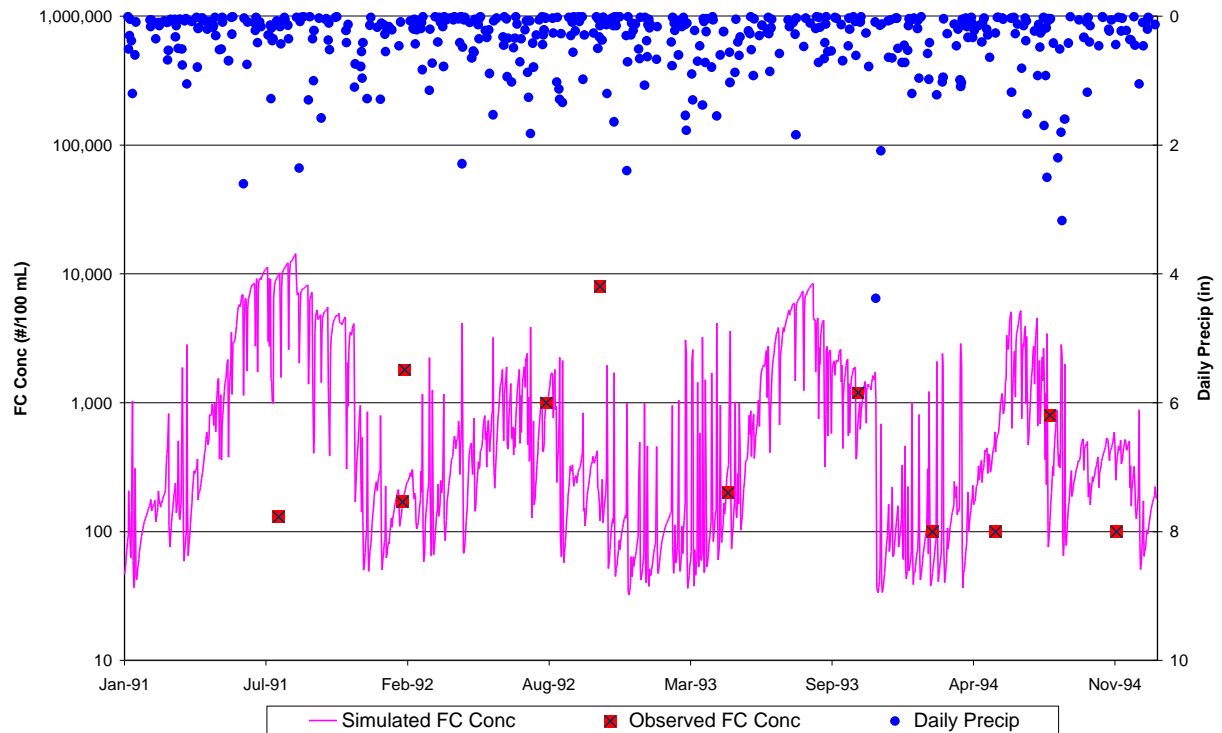


Figure 25. Observed and Simulated Fecal Coliform Concentrations for the Water Quality Calibration Period.

The geometric mean for the simulated data at the DEQ station for the entire calibration period is 449 cfu/100 mL; the geometric mean for the observed data for the same period at this station is 414 cfu/100 mL. The violations rate of the instantaneous interim fecal coliform water quality standard of 400 cfu/100 mL is 47% for the simulated data and 45% for the observed water quality data. The final parameters used in the calibration simulation are listed in Tables 44 and 45.

5. Load Allocations

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991).

5.1 Bacteria TMDL

5.1.1 Background

The objective of the bacteria TMDL for Cedar Run and Licking Run was to determine what reductions in fecal coliform and *E. coli* loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standards for *E. coli* used in the development of the TMDL were 126 cfu/100mL (calendar-month geometric mean) and 235 cfu/100mL (single sample maximum). The TMDL considers all sources contributing fecal coliform and *E. coli* to Cedar Run and Licking Run. The sources can be separated into nonpoint and point (or direct) sources. The incorporation of the different sources into the TMDL are defined in the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS} \quad \text{eq. 5.1}$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

While developing allocation scenarios to implement the bacteria TMDL, an implicit margin of safety (MOS) was used by using conservative estimations of the bacteria sources in the watershed (e.g., animal numbers, production rates, and contributions to streams). These factors were estimated in such a way as to represent the worst-case scenario; i.e., these factors would describe the worst stream conditions that could exist in the watershed. Creating a TMDL with these conservative estimates ensures that the

critical conditions in the stream have been considered and that no water quality standard violations will occur if the TMDL plan is followed.

For the Licking Run TMDL, the WLA was determined from the permitted point source discharger within the watershed. The contribution from this source was allocated at its permit limits. For the Cedar Run TMDL, the WLA was determined as the sum of the contributions from the MS4 areas and the permitted point source dischargers in each watershed. Contributions from the point sources were allocated at their permit limits. A clear permit limit was not defined for the MS4 areas. For this watershed, the WLA was set to the bacteria load expected to come from the MS4 areas. No reductions were required from this load because, in the portion of Prince William County covered by the Cedar Run watershed, contributions from impervious surfaces included in the MS4 permit were minor.

When developing a bacteria TMDL plan, the required bacteria load reductions are modeled by decreasing the amount of bacteria applied to the land surface and the amount of bacteria directly deposited in the stream; these reductions are presented in the Tables in Sections 5.1.3 and 5.1.2. In the model, this has the effect of reducing the amount of bacteria that reaches the stream, the ultimate goal of the TMDL. Thus, the reductions called for in Sections 5.1.3 and 5.1.2 indicate the need to decrease the amount of bacteria reaching the stream in order to meet the applicable water quality standard. The reductions shown in Sections 5.1.3 and 5.1.2 are not intended to imply that agricultural producers should reduce their herd size, or limit the use of manures as fertilizer or soil conditioner. Rather, it is assumed that the required reductions from affected agricultural source categories (cattle direct deposit, cropland, etc.) will be accomplished by implementing BMPs like filter strips, stream fencing, and off-stream watering; and that required reductions from residential source categories will be accomplished by repairing aging septic systems and other appropriate measures included in the TMDL Implementation Plan.

For both Cedar Run and Licking Run, a four year source allocation period was used. This period was selected because it incorporates average rainfall, low rainfall, and

high rainfall years; and the climate during this period caused a wide range of hydrologic events including both low and high flow conditions.

The calendar-month geometric mean values used in this report are geometric means of the simulated daily concentrations. Because HSPF was operated with a one-hour time step in this study, 24 hourly concentrations were generated each day. To estimate the calendar-month geometric mean from the hourly HSPF output, we took the arithmetic mean of the hourly values on a daily basis, and then calculated the geometric mean from these average daily values.

The guidance for developing an *E. coli* TMDL offered by VADEQ is to develop input for the model using fecal coliform loadings as the bacteria source in the watershed. Then, VADEQ suggests the use of a translator equation they developed to convert the in-stream daily average fecal coliform concentrations output by the model to daily average *E. coli* concentrations. The translator equation is:

$$E. coli \text{ concentration} = 2^{-0.0172} \times (\text{FC concentration})^{0.91905} \quad \text{eq. 5.2}$$

where the bacteria concentrations (FC and *E. coli*) are in cfu/100mL.

This equation was used to convert the fecal coliform concentrations output by HSPF to *E. coli* concentrations. Daily *E. coli* loads were obtained by using the *E. coli* concentrations calculated from the translator equation and multiplying them by the average daily flow. Annual loads were obtained by summing the daily loads and dividing by the number of years in the allocation period.

5.1.2 Licking Run Bacteria TMDL

5.1.2.a. Existing Conditions

Analysis of the simulation results for the existing conditions in the watershed (Table 47) show that cattle direct deposits of manure to streams is the primary source of *E. coli* in the stream, accounting for 81% of the mean daily *E. coli* in the stream. Loadings from wildlife direct deposit are the next largest contributors of *E. coli* in the stream, accounting for 12% of daily *E. coli* concentrations. Next comes pervious land

segments (manure applied to or deposited on cropland, pastures, and forests by livestock, wildlife, and other NPS sources) with 7% of the mean daily in-stream *E. coli* concentration. Nonpoint source loadings from impervious areas are responsible for less than 1% of the mean daily *E. coli* concentration and thus are not presented in Table 47.

Table 47. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the Licking Run watershed.

Source	Mean Daily <i>E. coli</i> Concentration by Source, cfu/100mL	Relative Contribution by Source
All sources	957	
Direct deposits of cattle manure to stream	776	81%
Direct nonpoint source loadings to the stream from wildlife	118	12%
Nonpoint source loadings from pervious land segments	63	7%

As shown in Table 47 direct *E. coli* loadings by cattle in the stream result in higher mean daily *E. coli* concentrations (957 cfu/100 mL) than do *E. coli* loadings from pervious upland areas (63 cfu/100 mL). The contribution of each of these sources to the calendar-month geometric *E. coli* concentration is shown in Figure 26. As indicated in this figure, the calendar-month geometric mean value is dominated by contributions from direct deposits of cattle to streams, and these deposits alone result in many violations of the calendar-month geometric mean goal of 126 cfu/100mL. In-stream *E. coli* concentrations from direct nonpoint sources, particularly cattle in streams, are highest during the summer when stream flows are lowest. This is expected because cattle spend more time in streams during the summer months; because of the low flow conditions, there is less stream flow for dilution of the direct deposit manure load. The same is true for the direct deposit from wildlife, to a lesser extent. The violations due to direct deposits from wildlife throughout the allocation period suggest that some reductions in wildlife loadings will be required in the final TMDL allocation. During wetter conditions, the contributions from wildlife become lower when compared to the contributions from pervious land segments (PLSs) to the calendar-month geometric mean. The contributions from pervious land segments to the calendar month geometric

mean concentration are less than to the daily average concentration because of the decrease in PLS contributions during non-runoff conditions between storm events, which reduces the calendar month geometric mean concentrations. Finally, the calendar-month geometric means for impervious land segments were so minor they were not included in Figure 26.

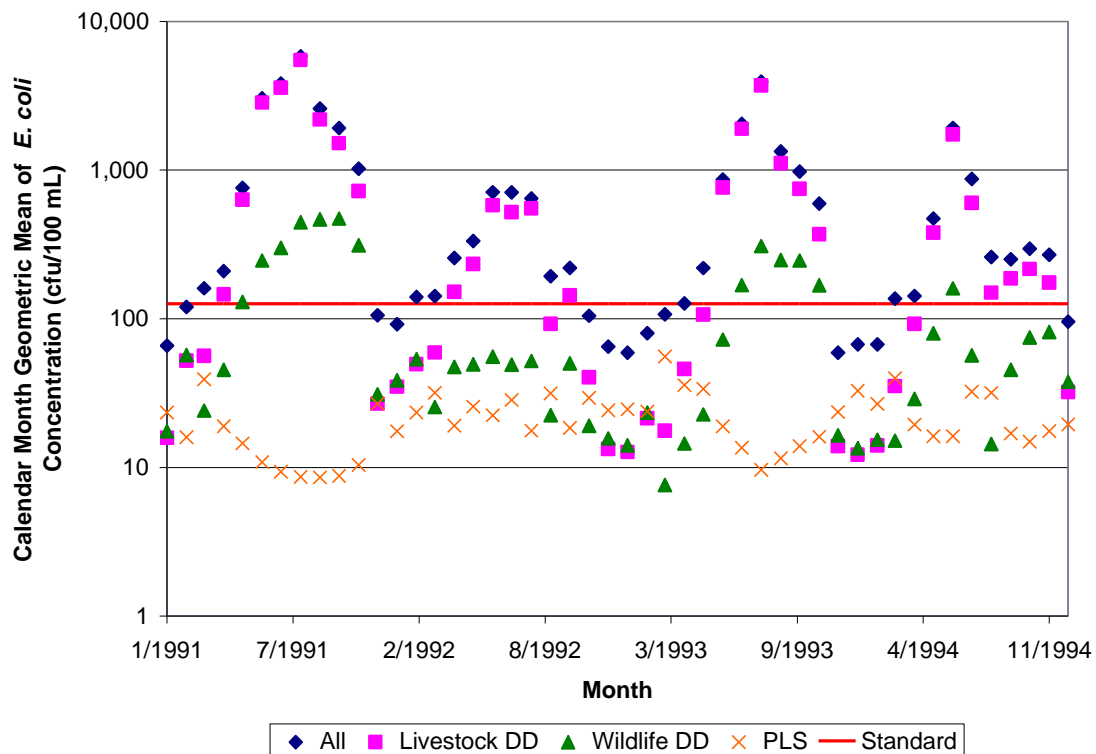


Figure 26. Relative contributions of different *E. coli* sources to the calendar-month geometric mean *E. coli* concentration for existing conditions in the Licking Run watershed.

5.1.2.b. Allocation Scenarios

A variety of allocation scenarios were evaluated to meet the *E. coli* TMDL goal of a calendar-month geometric mean of 126 cfu/100mL and a single sample limit of 235 cfu/100mL. The scenarios considered ran in parallel with the Cedar Run scenarios; i.e., Scenario 1 in Table 48 indicates that the reductions in Table 48 should be taken for sub-watersheds 06, 07, and 08 (Licking Run); and that the reductions from Scenario 01 in Table 54 would be taken from sub-watersheds 01, 02, 03, 04, 05, and 09 of Cedar Run when considering the Cedar Run violations. The scenarios and results are summarized in Table 48; recall that these reductions are those used for modeling, and implementation of

these reductions will require implementation of BMPs as discussed at the beginning of this chapter. Because direct deposition of *E. coli* by cattle into streams was responsible for 81% of the mean daily *E. coli* concentration (Table 47), and almost all of the violations, all scenarios considered required large reductions of direct deposits by cattle to the stream. For this watershed, the majority of violations occurred due to direct deposits at low flows that increased the simulated calendar-month geometric mean *E. coli* concentration. Therefore, it was impossible to meet the water quality standard without wildlife direct-deposit reductions, as can be seen from Scenario 2 in Table 48. This is not surprising, because the wildlife on their own cause violations of the geometric mean standard (see Figure 26). Once the direct deposit contributions were nearly eliminated (Scenario 3), the violations of the geometric mean standard were also eliminated. After this point, the reductions in PLS sources were scaled back, based on the violations of the instantaneous standard. As would be expected from inspection of Table 49, significant reductions in contributions from residential PLSs have little effect in reducing bacteria loadings to the stream; this can be seen in Scenario 4. Still, large reductions (95%) in pasture are required to meet the standards. Although Scenarios 3 and 4 meet water quality standards for Licking Run, the corresponding scenarios for Cedar Run (Scenario 3 and 4, Table 54) were not viable. In the interests of equity, further options were considered (Scenarios 5 and 6) that would more evenly distribute the weight of reductions between Cedar Run and Licking Run. Scenario 06 was selected as the successful allocation scenario for Licking Run because it required lower reductions than Scenario 5. The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 27 for the TMDL allocation (Scenario 06), along with the standards.

Table 48. Bacteria allocation scenarios for the Licking Run watershed.

Scenario Number	% Violations of <i>E. coli</i> Standard		Fecal Coliform Loading Reduction Required to Meet the <i>E. coli</i> Standards, %					
	Geomean	Single Sample	Cattle DD	Cropland	Pasture	Forest	Wildlife DD	All Residential PLSs
Existing Conditions	63	46	0	0	0	0	0	0
1	27	21	95	90	90	0	0	90
2	27	19	99	99	99	0	0	99
3	0	0	99	95	95	0	90	90
4	0	0	99	95	95	0	90	0
5	0	0	99	25	95	0	90	0
6	0	0	99	0	95	0	90	0

DD = direct deposit

PLSs = pervious land segments

Note: The shaded Allocation Scenarios (3 – 6) meet water quality standards.

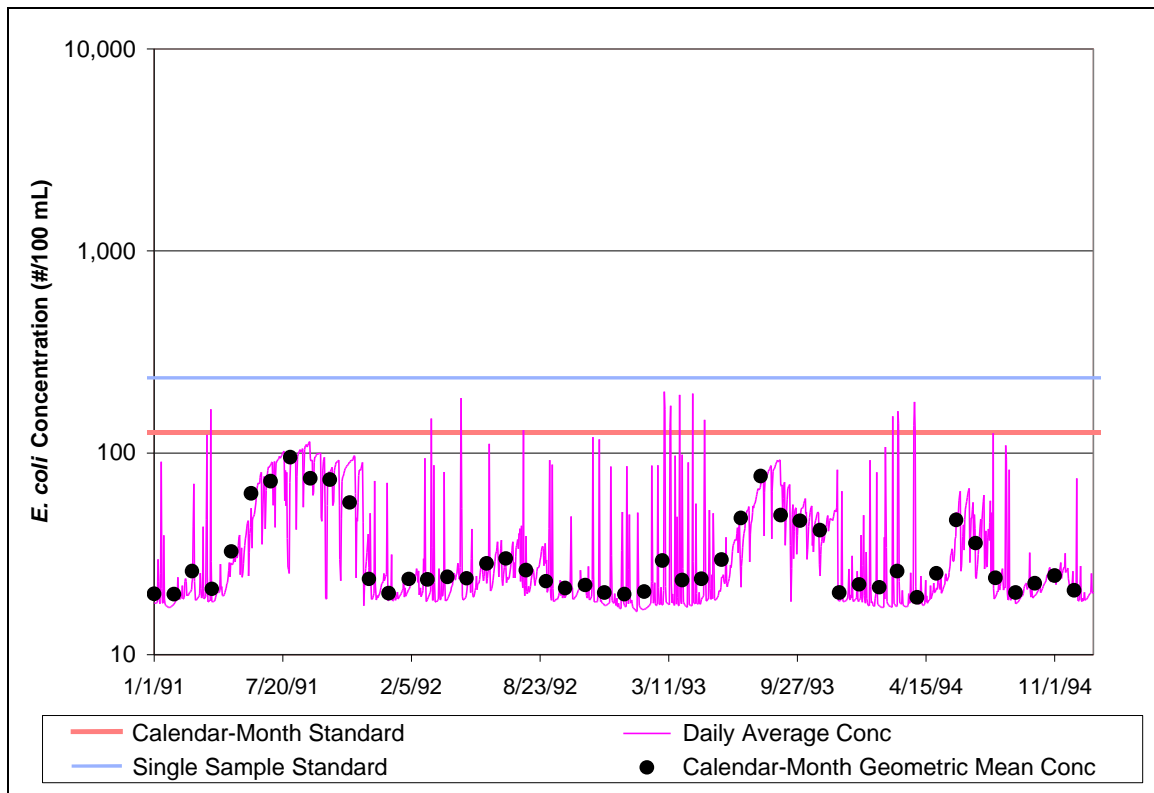


Figure 27. Calendar-month geometric mean standard, single sample standard, and successful *E. coli* TMDL allocation for Licking Run (Allocation Scenario 06 from * MERGEFORMAT Table 48.)

Loadings for existing conditions and for the successful TMDL allocation scenario (Scenario 6) are presented for nonpoint sources by land use in Table 49 and for direct

nonpoint sources in Table 50. It is clear that extreme reductions in both loadings from land surfaces and from sources directly depositing in the streams of Licking Run are required to meet both the calendar-month geometric mean and single sample standards for *E. coli*. Cattle deposition directly in streams dominates the *E. coli* contributions to the stream, particularly during the summer months when cattle spend more time in the stream, flows are lower, and there is minimal dilution due to reduced stream flow. Loadings from upland areas are lower during these periods because there is little upland runoff to transport fecal coliform to streams. When high flow conditions do occur, however, the large magnitude of the nonpoint source loadings coming from upland areas result in violations of the water quality standard. Because these upland loadings are intermittent, they are not a primary source of violations of the calendar-month geometric mean standard, but do cause many violations of the *E. coli* single sample standard.

Table 49. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for the TMDL allocation scenario (Scenario 06) for Licking Run.

Land use Category	Existing Conditions		Allocation Scenario	
	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	127	2	127	0
Pasture	7,090	95	355	95
Residential	74.7	1	74.7	0
Forest	150	2	150	0
Total	7440	100	707	90

Table 50. Annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for the TMDL allocation scenario (Scenario 06).

Source	Existing Condition		Allocation Scenario	
	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total direct deposited load from direct nonpoint sources	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction
Cattle in streams	36.7	83	0.367	99
Wildlife in Streams	7.6	17	0.76	90
Total	44.3	100	1.13	97

The fecal coliform loads presented in Table 50 and Table 51 are the fecal coliform loads that result in in-stream *E. coli* concentrations that meet the applicable *E. coli* water quality standards after application of the VADEQ fecal coliform to *E. coli* translator to the HSPF predicted mean daily fecal coliform concentrations.

5.1.2.c. Waste Load Allocation

A waste load allocation was assigned to the one permitted point source facility in the Licking Run watershed (Table 51). The point source was represented in the allocation scenarios by its current permit conditions; no reductions were required from the point source in the TMDL. Current permit requirements are expected to result in attainment of the *E. coli* WLA as required by the TMDL. Point source contributions, even in terms of maximum flow, are minimal. Therefore, no reasonable potential exists for these facilities to have a negative impact on water quality and there is no reason to modify the existing permits. The point source facility is discharging at its criteria and therefore cannot cause violations of the water quality criteria.

Table 51. Point Source Discharging Bacteria in the Licking Run Watershed.

Permit Number	Facility	Flow (MGD)	Permitted FC Conc.	Permitted FC Load (cfu/year)	Allocated FC Load (cfu/year)	Allocated <i>E. coli</i> Load (WLA) (cfu/year)
VA0084298	Smith Midland Incorporated	0.0015	200 cfu/100 mL	4.15E+09	4.15E+09	2.61E+09

5.1.2.d. Summary of Licking Run's TMDL Allocation Scenario for Bacteria

A TMDL for *E. coli* has been developed for Licking Run. The TMDL addresses the following issues:

1. The TMDL meets the calendar-month geometric mean and single sample water quality standards.
2. Because *E. coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was then used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations for which the bacteria TMDL was developed.
3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.
4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.
5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Licking Run watershed, low stream flow was found to be the environmental condition most likely to cause violations of the geometric mean criteria of the standard. Furthermore, violations of the instantaneous criteria of the standard were generally associated with storm flows and some high stream flow conditions.
6. Both the flow regime and bacteria loading to Licking Run are seasonal. The TMDL accounts for these seasonal effects.

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 99% reduction in direct deposits of cattle manure to streams, a 90% reduction in direct deposits by wildlife to

streams, no reductions in loadings to cropland, and a 95% reduction in nonpoint source loadings to pastures. No reductions in loadings to residential land surfaces are required. Using Eqn. 1, the summary of the bacteria TMDL for Licking Run for the selected allocation scenario (Scenario 6) is given in Table 52. In Table 52, the WLA was obtained by summing the products of each permitted point source's fecal coliform discharge concentration and allowable annual discharge. The LA is then determined as the TMDL – WLA.

Table 52. Annual *E. coli* loadings (cfu/year) used for the Licking Run bacteria TMDL.

Parameter	SWLA	SLA	MOS*	TMDL
<i>E. coli</i>	2.6×10^9 (VA0084298 = 2.61×10^9)	$9,634 \times 10^9$	--	$9,637 \times 10^9$

*Implicit Margin of Safety

5.1.3 Cedar Run Bacteria TMDL

5.1.3.a. Existing Conditions

Analysis of the simulation results for the existing conditions in the watershed (Table 53) show that direct deposits from livestock are the primary source of *E. coli* in the stream. These direct deposits account for approximately 65% of the mean daily *E. coli* concentration in the stream. Feces directly deposited by wildlife in the stream constitute the next largest contribution at 26% of the mean daily *E. coli* concentration. Contributions from the upland pervious land segments account for approximately 8% of the concentration at the watershed outlet. Runoff from impervious areas contributed less than 1% of the mean daily *E. coli* concentration and is not listed in Table 53.

The contribution of each of the sources detailed in Table 53 to the calendar-month geometric *E. coli* concentration is shown in Figure 28. As indicated in this figure, the calendar-month geometric mean value is dominated by contributions from direct deposits of cattle to streams, and these deposits alone result in violations of the calendar-month geometric mean goal of 126 cfu/100mL. Additionally, contributions from direct deposits of wildlife to streams alone result in violations of the calendar-month geometric mean standard. Because contributions from upland areas decrease during non-runoff conditions between storm events, the contributions from the upland pervious areas to

violations of the calendar month geometric mean *E. coli* concentration are much less than their contributions to violations of the daily average concentration (single sample standard). For the same reason, ILS contributions to the calendar month geometric mean concentrations are too small to be represented in Figure 28. In-stream *E. coli* concentrations from direct nonpoint sources, particularly cattle in streams, are highest during the summer when stream flows are lowest. This is expected because cattle spend more time in streams during the summer months; because of the low flow conditions, there is less stream flow for dilution of the direct deposit manure load.

Table 53. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the Cedar Run watershed.

Source	Mean Daily <i>E. coli</i> Concentration by Source, cfu/100mL	Relative Contribution by Source
All Sources	808	
Direct deposits of cattle manure to stream	529	65%
Direct nonpoint source loadings to the stream from wildlife	213	26%
Nonpoint source loadings from pervious land segments	66	8%

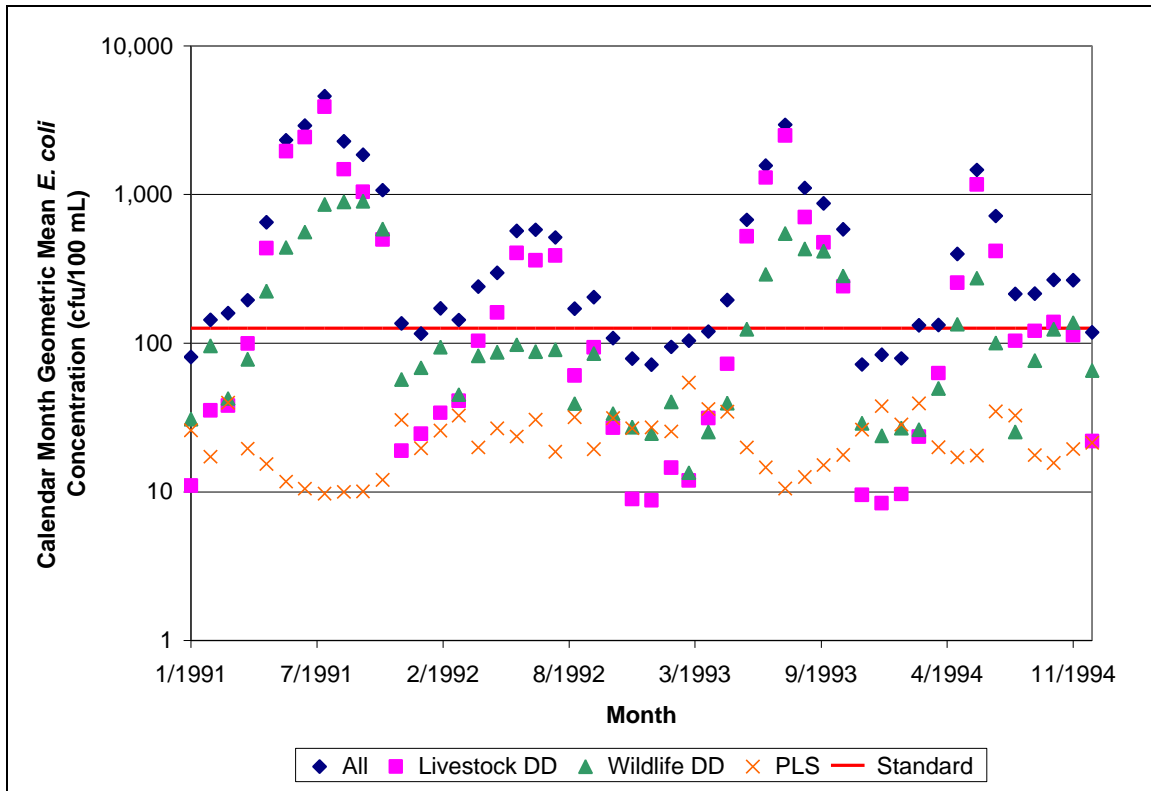


Figure 28. Relative contributions of different *E. coli* sources to the calendar-month geometric mean *E. coli* concentration for existing conditions in the Cedar Run watershed.

5.1.3.b. Allocation Scenarios

A variety of allocation scenarios were evaluated to meet the *E. coli* TMDL goal of a calendar-month geometric mean of 126 cfu/100mL and the single sample limit of 235 cfu/100mL. The scenarios considered ran in parallel with the Licking Run scenarios; i.e., Scenario 1 in Table 54 indicates that the reductions in Table 54 should be taken from sub-watersheds 01, 02, 03, 04, 05, and 09 and that the reductions from Scenario 1 in Table 48 should be taken for sub-watersheds 06, 07, and 08. The scenarios and results for the Cedar Run allocation scenarios are summarized in Table 54; recall that these reductions are those used for modeling, and implementation of these reductions will require implementation of BMPs as discussed at the beginning of this chapter. Because direct deposition of *E. coli* by cattle into streams was responsible for 65% of the mean daily *E. coli* concentration (see Table 53) and the vast majority of the calendar-month geometric

mean concentration, all scenarios considered required reductions in or elimination of direct deposits by cattle.

In all scenarios considered in Table 54, nonpoint source contributions from impervious land segments were not considered for reduction because their contribution to the calendar-month geometric mean and the daily average concentrations is negligible (Table 53, Figure 28). In scenario 1, large reductions (at least 90%) were taken from all anthropogenic sources. This decreased the violations rates of both the calendar month geometric mean and instantaneous standards significantly, but still the violations rates were high (Table 54). Scenario 2 increased all anthropogenic source reductions to 99% but still resulted in significant standards violations, dropping the violations rate only by 6% for the geometric mean and 2% for the instantaneous standards, respectively. This indicated the need to call for reductions from wildlife; this is not unexpected as the contributions from wildlife alone were shown to violate the geometric mean standard as shown in Figure 29. Scenario 3 increased wildlife reductions to 90%, but the reductions were still not enough to bring the violations of the geometric mean standard to zero. Wildlife reductions were increased for Scenario 4, with a decrease in residential reductions. The increase in wildlife reductions eliminated the geometric mean violations; however, the decrease in residential reductions allowed violations of the instantaneous standard to occur. Scenarios 5 and 6 were both successful allocation scenarios. They correspond with Scenarios 5 and 6 in the Licking Run discussion (Table 48). As can be seen from Table 55, residential loadings are more than twice as large as the cropland loadings; therefore, Scenario 6 was chosen as the preferred allocation scenario, as it addressed the larger source contribution. The concentrations for the calendar-month geometric mean and daily average *E. coli* values are shown in Figure 29 for the TMDL allocation (Scenario 06), along with the standards.

Table 54. Bacteria allocation scenarios for the Cedar Run watershed.

Scenario Number	% Violations of <i>E. coli</i> standard		Required Fecal Coliform Loading Reductions to Meet the <i>E. coli</i> Standards,%					
	Geomean	Single Sample	Cattle DD	Cropland	Pasture	Forest	Wildlife DD	All Residential PLS
Existing Conditions	75	51	0	0	0	0	0	0
1	44	27	95	90	90	0	0	90
2	38	25	99	99	99	0	0	99
3	4	0	99	95	95	0	90	95
4	0	1	99	95	95	0	95	0
5	0	0	99	95	95	0	95	25
6	0	0	99	0	95	0	95	95

Note: The shaded Allocation Scenarios (5 – 6) meet water quality standards.
DD = direct deposit

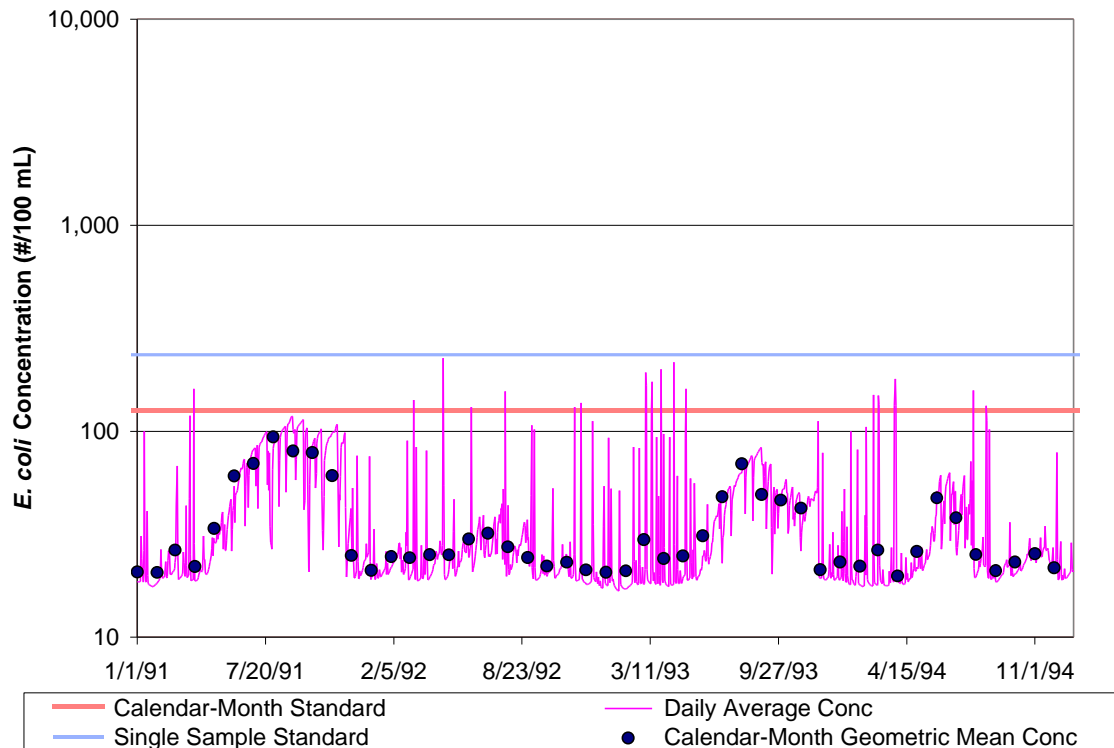


Figure 29. Calendar-month geometric mean standard, single sample standard, and successful *E. coli* TMDL allocation (Allocation Scenario 06 from Table 54) for Cedar Run.

Loadings for existing conditions and the TMDL allocation scenario (Scenario 06) are presented for nonpoint sources by land use in Table 55 and for direct nonpoint sources in Table 56. It is clear that extreme reductions in both loadings from land

surfaces and from sources directly depositing in the streams of Cedar Run are required to meet both the calendar-month geometric mean and single sample standards for *E. coli*. Cattle deposition directly in streams dominates the *E. coli* contributions to the stream, particularly during the summer months when cattle spend more time in the stream, flows are lower, and there is minimum dilution due to reduced stream flow. Loadings from upland areas are reduced during these periods because there is little upland runoff to transport fecal coliform to streams. When high flow conditions do occur, however, the large magnitude of the nonpoint source loadings coming from upland areas becomes a major contributor to the in-stream concentration. Because these upland loadings are intermittent, they are not a primary source of violations of the calendar-month geometric mean standard, but do cause many violations of the *E. coli* single sample standard.

Table 55. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for the TMDL allocation scenario (Scenario 06) for Cedar Run.

Land use Category	Existing Conditions		Allocation Scenario	
	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	767	1	767	0
Pasture	53,900	93	2,700	95
Residential	1,560	3	78	95
Forest	2,010	3	2,010	0
Total	58,200	100	5,560	90

Table 56. Annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for the TMDL allocation scenario (Scenario 06) for Cedar Run.

Source	Existing Condition		Allocation Scenario	
	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total direct deposited load from direct nonpoint sources	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction
Cattle in streams	160	62%	1.6	99
Wildlife in Streams	100	38%	5	95
Total	260	100%	6.6	97

The fecal coliform loads presented in Table 55 and Table 56 are the fecal coliform loads that result in in-stream *E coli* concentrations that meet the applicable *E coli* water quality standards after application of the VADEQ fecal coliform to *E coli* translator to the HSPF predicted mean daily fecal coliform concentrations.

5.1.3.c. Waste Load Allocation

Waste load allocations were assigned to the fourteen point source facilities located in the Cedar Run watershed (Table 57), as well as the two MS4 areas. The point sources were represented in the allocation scenarios by their current permit conditions; no reductions were required from the point sources in the TMDL. Current permit requirements are expected to result in attainment of the *E. coli* WLA as required by the TMDL. Point source contributions, even in terms of maximum flow, are minimal. Therefore, no reasonable potential exists for these facilities to have a negative impact on water quality and there is no reason to modify the existing permits. The point source facilities are discharging at their criteria and therefore do not cause a violation of the water quality criteria. Note that the *E. coli* WLA value presented in Table 58 represents the sum of all point source *E. coli* WLAs in Cedar Run.

5.1.3.d. Summary of Cedar Run's TMDL Allocation Scenario for Bacteria

A TMDL for *E. coli* has been developed for Cedar Run. The TMDL addresses the following issues:

1. The TMDL meets the calendar-month geometric mean and single sample water quality standards.
2. Because *E coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was then used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E coli* concentrations for which the bacteria TMDL was developed.

3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.

Table 57. Point Sources Discharging Bacteria in the Cedar Run Watershed.

Permit Number	Facility	Flow (MGD)	Permitted FC Conc.	Permitted FC Load (cfu/year)	Allocated FC Load (cfu/year)	Allocated <i>E. coli</i> Load (WLA) (cfu/year)
VA0028371	US Marine Corps - Quantico	0.04	200 cfu/100 mL	1.11E+11	1.11E+11	6.97E+10
VA0027278	Pearson Elementary	0.0079	200 cfu/100 mL	2.18E+10	2.18E+10	1.38E+10
VA0084298	Smith Midland Incorporated	0.0015	200 cfu/100 mL	4.15E+09	4.15E+09	2.61E+09
VAG406075	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406089	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406090	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406091	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406108	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406126	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406188	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406192	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406210	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406267	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VAG406317	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09

Permit Number	Facility	Flow (MGD)	Permitted FC Conc.	Permitted FC Load (cfu/year)	Allocated FC Load (cfu/year)	Allocated <i>E. coli</i> Load (WLA) (cfu/year)
VAG406323	General Permit Facility	0.001	200 cfu/100 mL	2.76E+09	2.76E+09	1.74E+09
VA0088595 and VAR040100	MS4 Permits	NA	NA	NA	5.25E+11 ^a	4.52E+11 ^a

^a The MS4 portion of the WLA was determined by ‘turning off’ all bacteria sources in the model other than those coming from the impervious surfaces in the MS4 areas; the resulting model output concentration timeseries was multiplied by the output flow timeseries to yield a load timeseries that was averaged to represent an annual load and included here.

4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.
5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Cedar Run watershed, low stream flow was found to be the environmental condition most likely to cause violations of the geometric mean criteria of the standard. Furthermore, violations of the instantaneous criteria of the standard were generally associated with storm flows and some high stream flow conditions.
6. Both the flow regime and bacteria loading to Cedar Run are seasonal. The TMDL accounts for these seasonal effects.

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 99% reduction in direct deposits of cattle manure to streams, a 95% reduction in direct deposits of wildlife feces to streams, a 95% reduction in nonpoint source loadings to pastures and residential areas, and no reduction in nonpoint source loadings to cropland. These reductions apply only to the non-Licking Run portions of the watershed; the reductions from the Licking Run successful TMDL scenario (Table 48) are also required in order for Cedar Run to meet the water quality standards. Using Eq. [5.1], the summary of the bacteria TMDL for

Cedar Run for the selected allocation scenario (Scenario 06) is given in Table 58. In Table 58, the WLA was obtained by multiplying the permitted point sources' fecal coliform discharge concentrations by their allowable annual discharge; the MS4 portion of the WLA was determined by isolating the contribution of the MS4 areas to the bacteria output from the HSPF model. The LA is then determined as the TMDL – WLA.

Table 58. Annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Cedar Run bacteria TMDL.

Watershed	Parameter	SWLA	SLA	MOS*	TMDL
<i>Cedar Run Excluding Licking Run</i>	<i>E. coli</i>	55.5×10^{10} (VA0027278 = 1.38×10^{10} ; VA0028371 = 6.97×10^{10} ; SSFH WLA = 2.09×10^{10} ; SMS4 area = 4.51×10^{11})	$6,966 \times 10^{10}$	--	$7,021 \times 10^{10}$
<i>Cedar Run Including Licking Run</i>	<i>E. coli</i>	58.2×10^{10} (VA0027278 = 1.38×10^{10} ; VA0028371 = 6.97×10^{10} ; VA0084298 = 2.61×10^9 ; SSFH WLA = 2.09×10^{10} ; SMS4 area = 4.51×10^{11})	$7,931 \times 10^{10}$	--	$7,989 \times 10^{10}$

*Implicit Margin of Safety

6. TMDL Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on Cedar and Licking Run. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent “TMDL Implementation Plan Guidance Manual”, published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at <http://www.deq.state.va.us/tmdl/implans/ipguide.pdf> With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

6.1 Staged Implementation

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In the Licking and Cedar Run watersheds a number of failing septic systems have been documented over time. While the loads in by themselves do not constitute a majority of the contamination problem, they do represent a potentially serious health issue. Additionally, the majority of the systems currently installed are becoming aged and it is anticipated that left unchecked the potential for contamination will only increase with time. The staged implantation efforts should address these septic issues concurrently with the agricultural issues.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Because this watershed is currently undergoing a transformation from an agricultural dominated land use pattern to an urban land use, it is anticipated that the sources of contamination will shift over time. As such the staged implementation plan will allow for flexibility in addressing the prevalent sources. Similarly within the agricultural community the prevalence of a milk based cattle population is being supplanted by a beef based population which may require different implementation efforts.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

6.2. Stage 1 scenarios

The goal of the stage 1 scenarios is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the instantaneous criterion (235 cfu/100mL) are less than 10 percent. Alternatively, if it is not possible to reduce violations of the instantaneous criterion to less than 10% without reducing wildlife, the stage 1 scenario shall be identical to the TMDL scenario, with the exception that no wildlife reductions shall be required. This latter goal was used for both Licking and Cedar Runs, as elimination of wildlife reductions caused a greater than 10% violation rate for both watersheds. The stage 1 scenarios were generated with the same model setup as was used for the TMDL allocation scenarios. A margin of safety was not used in determining the stage 1 scenarios. It was estimated for modeling purposes that there are no straight pipes in the Licking and Cedar Run watersheds. Should any be found during the implementation process, they should be eliminated as soon as possible since they would be illegally discharging fecal bacteria into Licking and Cedar Runs and their tributaries.

6.2.1. Licking Run Scenario

Scenario 01 in Table 59 was chosen as the final Stage 1 implementation scenario because it requires no reductions from wildlife and because the reductions to other sources correspond to those required for the selected TMDL allocation scenario (Scenario 06, Table 48). Scenario 01 requires a 99% reduction in direct deposits by cattle to streams, no reduction in loadings from cropland, and a 95% reduction in loadings from pastures. No reduction in wildlife deposits to the stream is required. Fecal coliform loadings for the existing conditions and for the Stage 1 allocation scenario for nonpoint sources by land use are presented in Table 60 and for direct nonpoint sources in Table 61. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the Scenario 01 fecal coliform loads are presented graphically in Figure 30.

Table 59. Allocation scenarios for Stage 1 TMDL implementation for Licking Run.

Scenario Number	Single Sample % Violations	% Reduction Required				
		Cattle DD	Cropland	Pasture	Wildlife DD	All Residential PLS
01	19	99	0	95	0	0

DD = direct deposit

Table 60. Annual nonpoint source load reductions for Stage 1 TMDL implementation for Licking Run watershed (Scenario 01).

Land use Category	Existing Conditions		Allocation Scenario	
	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total land deposited load from nonpoint sources	Nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	127	2	127	0
Pasture	7,090	95	355	95
Residential	74.7	1	74.7	0
Forest	150	2	150	0
Total	7440	100	707	90

Table 61. Required direct nonpoint source fecal coliform load reductions for Stage 1 Implementation Scenario (Scenario 01).

Source	Existing Condition		Allocation Scenario	
	Existing condition load ($\times 10^{12}$ cfu)	Percent of total direct deposited load from direct nonpoint sources	Direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cattle in streams	36.7	83	0.367	99
Wildlife in Streams	7.6	17	7.6	0
Total	44.3	100	7.97	82

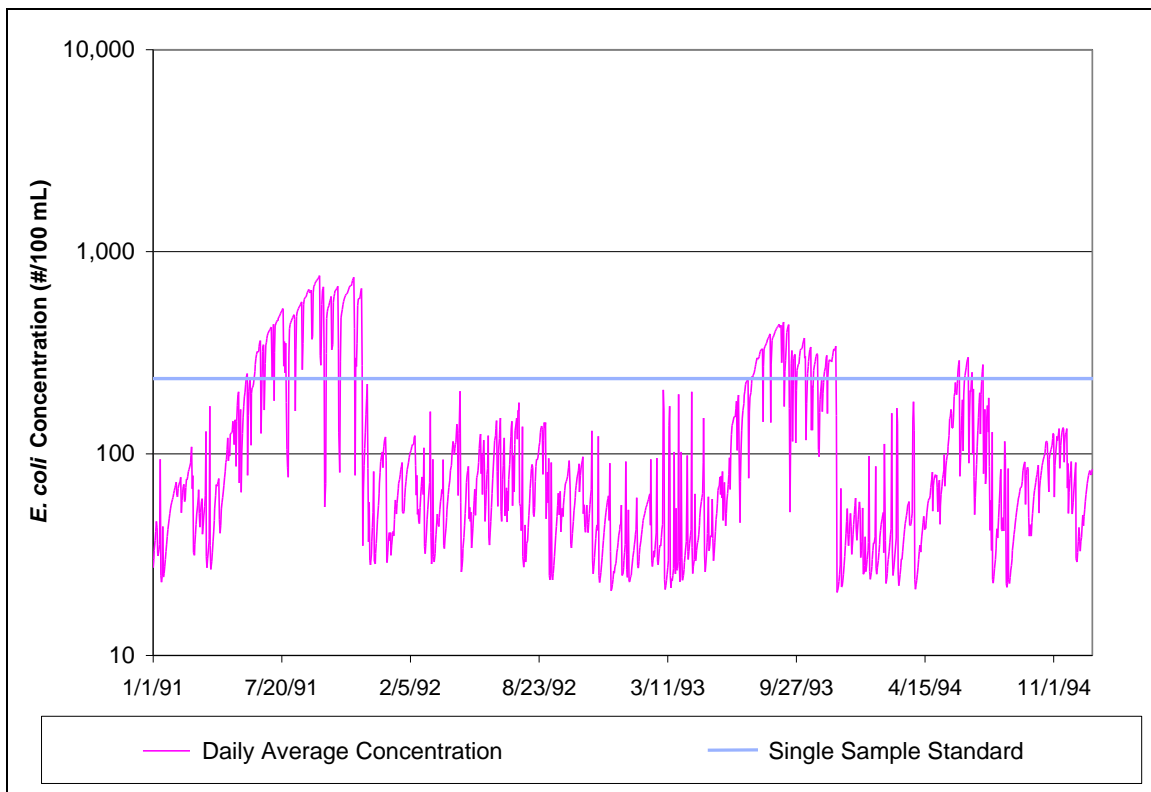


Figure 30. Stage 1 TMDL implementation scenario for Licking Run.

6.2.2. Cedar Run Scenario

Scenario 01 in Table 62 was chosen as the final Stage 1 implementation scenario because it requires no reductions from wildlife and because the reductions to other sources correspond to those required for the selected TMDL allocation scenario (Scenario 06, Table 54). Scenario 01 requires a 99% reduction in direct deposits by cattle to streams, reductions (95%) in loadings from pastures and residential surfaces, and no reductions from cropland. No reduction in wildlife deposits to the stream is required. Fecal coliform loadings for the existing conditions and the Stage 1 allocation scenario for nonpoint sources by land use are presented in Table 63 and for direct nonpoint sources in Table 64. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the Scenario 01 fecal coliform loads are presented graphically in Figure 31.

Table 62. Allocation scenarios for Stage 1 TMDL implementation for Cedar Run.

Scenario Number	Single Sample % Violations	% Reduction Required					
		Cattle DD ¹	Cropland	Pasture	Forest	Wildlife DD	All Residential PLS
01	25	99	0	95	0	0	95

DD = direct deposit

Table 63. Annual nonpoint source load reductions for Stage 1 TMDL implementation for the Cedar Run watershed (Scenario 01).

Land use Category	Existing Conditions		Stage 1 Allocation Scenario	
	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total land deposited load from nonpoint sources	Nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	767	1	767	0
Pasture	53,900	93	2,700	95
Residential	1,560	3	78	95
Forest	2,010	3	2,010	0
Total	58,200	100	5,560	90

Table 64. Required direct nonpoint source load reductions for Stage 1 Implementation (Scenario 01).

Source	Existing Condition		Allocation Scenario	
	Existing condition load ($\times 10^{12}$ cfu)	Percent of total direct deposited load from direct nonpoint sources	Direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cattle in streams	160	62	1.6	99
Wildlife in Streams	100	38	100	0
Total	260	100	102	61

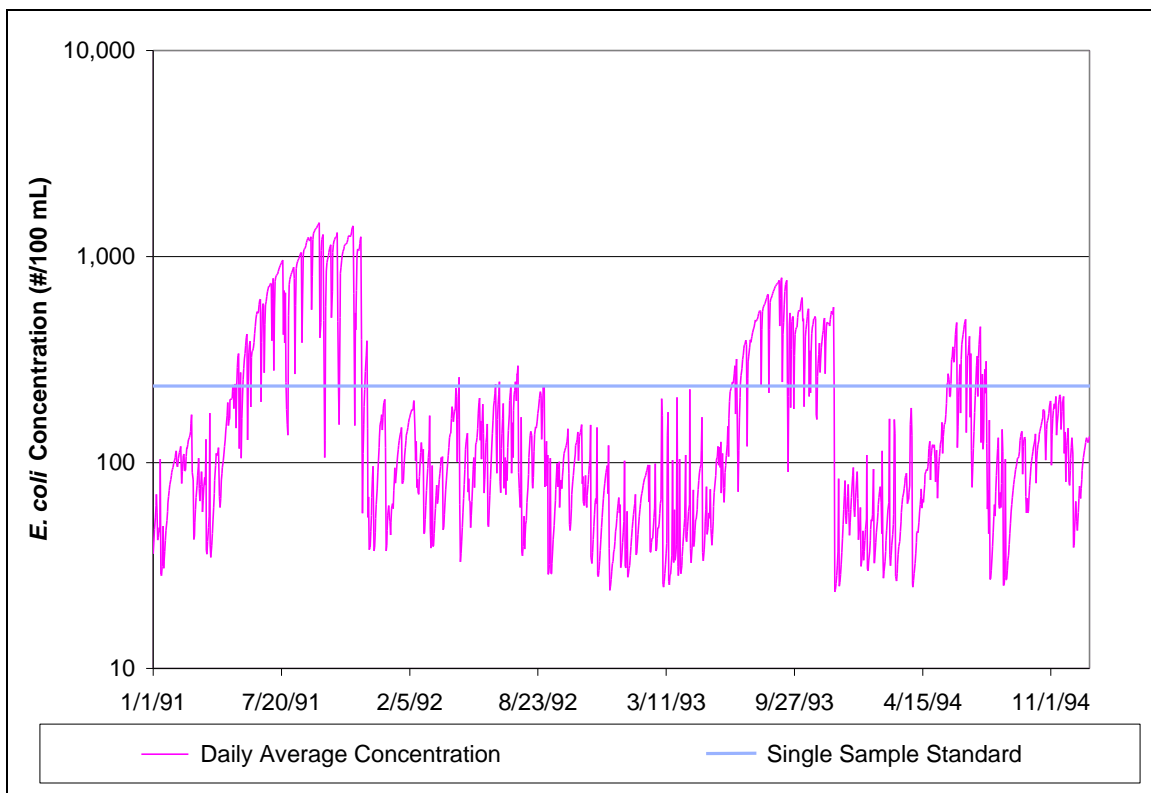


Figure 31. Stage 1 TMDL implementation scenario for Cedar Run.

6.3 Link to ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria have also been identified for

implementation as part of the 2001 Interim Nutrient Cap Strategy for the Shenandoah/Potomac basin. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. (2001 Draft Interim Nutrient Cap Strategy for the Shenandoah/Potomac River Basins). A new tributary strategy is currently being developed for the Shenandoah-Potomac River Basin to address the nutrient and sediment reductions required to restore the health of the Chesapeake Bay. Up-to-date information can be found at the Commonwealth of Virginia's tributary strategy web site under <http://www.snr.state.va.us/Initiatives/TributaryStrategies/shenandoah.cfm>.

6.4 Reasonable Assurance for Implementation

6.4.1 Follow-Up Monitoring

VADEQ will continue monitoring Cedar Run (1ACER0025.25, 1ACER016.46, 1ACER009.52, and 1ACER006.00) and Licking Run (1ALIL001.43) in accordance with its ambient monitoring program to evaluate reductions in fecal bacteria counts, and also the effectiveness of TMDL implementation in attainment of water quality standards.

6.4.2 Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The

listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

6.4.3 Stormwater Permits

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is the Virginia Pollutant Discharge Elimination System (VPDES) Permit Regulation (9 VAC 25-31-10 et seq.). Section 9 VAC 25-31-120 describes the requirements for storm water discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when:...(2) Numeric effluent limitations are infeasible,...".

Part of the Cedar Run watershed is covered by a Phase I VPDES permit, VA0088595, for the municipal separate storm sewer system (MS4) owned by Prince William County. Part of this Prince William County areas is also covered by a Phase II VPDES permit, VAR040100, for the small municipal separate storm sewer system (MS4) owned by the Prince William County Schools. Prince William County's Phase I permit was reissued on February 5, 2003 and the Schools' Phase II permit was issued on December 30, 2003. The county permit's effective date of coverage is February 5, 2003,

and the school system's effective date of coverage is December 9, 2002. The permits require, under Parts I.A.2 and II.A., respectively, that the permittee develop, implement, and enforce a storm water management program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Clean Water Act and the State Water Control Law. The permits also contain TMDL clauses that state that the permits will be reopened if a TMDL wasteload allocation imposes limits or conditions on the facility that are not consistent with the permit requirements.

For both Phase I and Phase II MS4 permits, DEQ expects revisions to the permittee's Stormwater Pollution Prevention Plans to specifically address the TMDL pollutants of concern through the implementation of BMPs. DEQ anticipates that BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its BMPs to achieve the TMDL reductions. However, only failing to implement the required BMPs would be considered a violation of the permit. DEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs. At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from a water quality standard change on Cedar Run would be reflected in the permittee's Stormwater Pollution Prevention Plan required by the MS4/VPDES permit.

6.4.4 Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan

Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

6.4.5 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. As is the case for Cedar Run and Licking Run, these streams may not be able to attain standards without some reduction in wildlife load. Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia has proposed (during its recent triennial water quality standards review) a new “secondary contact” category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for “secondary contact recreation” which means “a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)”. These new criteria became effective February 12, 2004 and can be found at <http://www.deq.state.va.us/wqs/rule.html>.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment

during this process. Additional information can be obtained at <http://www.deq.state.va.us/wqs/WQS03AUG.pdf>

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in section 6.1 above. DEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard violations attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

7. Public Participation

The development of the Cedar and Licking Run TMDLs would not have been possible without public participation. The first public meeting was held at the Catlett Volunteer Fire Department Hall in Catlett on July 10, 2003 to discuss the need for a TMDL and the process for TMDL development. Thirty-four people attended. Copies of the presentation materials were available for public distribution. A public notice of the meeting was printed in the Virginia Register, as well as in the Fauquier Times-Democrat and the Bull Run Observer. In addition, flyers inviting the public to attend the meeting were distributed through the John Marshall and Prince William Soil and Water Conservation District offices, and posted at various locations around the watershed. A postcard mailing announcing the meeting was sent to watershed residents, and the meeting was advertised on the VADEQ website. There was a 30-day public comment period and one written comment was received.

The second public meeting was held at the Nokesville Elementary School in Nokesville on October 23, 2003 to discuss the draft watershed source assessment and to review the approach for TMDL development. Twenty-seven people attended. Public notice of the meeting was printed in the Virginia Register and included in the community calendars of the Fauquier Times-Democrat and the Bull Run Observer, the meeting was also advertised on the VADEQ website. In addition, flyers inviting the public to attend the meeting were distributed through the John Marshall and Prince William Soil and Water Conservation District offices, and posted at various locations around the watershed. There was a 30-day public comment period and two written comments were received.

The third and final public meeting was held at the H.M. Pearson Elementary School in Calverton on March 23, 2004 to discuss the source allocations and reductions required to meet the TMDL. Twenty-one people attended. Copies of the draft TMDL report were available for public review and comment. Public notice of the meeting was printed in the Virginia Register and included in the community calendars of the Fauquier Citizen, Fauquier Times-Democrat and the Bull-Run Observer. A postcard mailing announcing

the meeting was sent to watershed residents and a newsletter announcing the meeting was sent to area appointed and elected officials and prior meeting attendees. There was a 30-day public comment period and two written comments were received.

In addition to keeping the public apprised of progress in the development of the Cedar and Licking Run TMDL, a TAC was also established to help advise the TMDL developers. TAC meetings were generally held two to three weeks prior to public meetings. Due to scheduling difficulties, the final TAC meeting was held after the final public meeting, and the TAC did not have the opportunity to review the draft report before the public meeting. TAC comments on the draft report were, however, incorporated into the final report before submittal to EPA. The TAC membership included representatives from the following agencies and organizations:

- Virginia Department of Environmental Quality
- Virginia Department of Conservation and Recreation
- Fauquier County Planning
- Prince William County, Office of Watersheds
- John Marshall SWCD
- Prince William SWCD
- VA Cooperative Extension
- Occoquan Watershed Monitoring Laboratory

The TAC meetings were used as a forum to review data and assumptions used in the modeling, and to provide local government agencies an opportunity to raise concerns about the implications of the TMDL for their jurisdictions. The generous assistance of the staff of these agencies is gratefully acknowledged.

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Appendix A. Glossary of Terms

Allocation

That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario

A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels

Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)

A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)

Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bacteria Source Tracking

A collection of scientific methods used to track sources of fecal coliform.

Calibration

The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Die-off (of fecal coliform)

Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH).

Direct nonpoint sources

Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

E-911 digital data

Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

Geometric mean

The geometric mean is simply the n th root of the product of n values. Using the geometric mean, lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, \bar{x}_g , is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \dots x_n}$$

where n is the number of samples, and x_i is the value of sample i .

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

Hydrology

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violations of the state water quality standard.

Load allocation (LA)

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model

Mathematical representation of hydrologic and water quality processes. Effects of Land use, slope, soil characteristics, and management practices are included.

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system

An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives liquid and solid wastes from a residence or business and a drainfield or subsurface absorption system consisting of a series of tile or percolation lines for disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Simulation

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

For more definitions, see the Virginia Cooperative Extension publications available online:

Glossary of Water-Related Terms. Publication 442-758.

<http://www.ext.vt.edu/pubs/bse/442-758/442-758.html> and TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Publication 442-550.

<http://www.ext.vt.edu/pubs/bse/442-550/442-550.html>

Appendix B. Sample Calculation of Distribution of Cattle

Sample Calculation: Distribution of Cattle

(During January)

(Note: Due to rounding, the numbers may not add up.)

Breakdown of the dairy herd is 96 milk cows, 20 dry cows, and 95 heifers.

1. During January, milk cows are confined 75% of the time. Dry cows and heifers are confined 40% of the time.

$$\text{Milk cows in confinement} = 96 * (75\%) = 72$$

$$\text{Dry cows in confinement} = 20 * (40\%) = 8$$

$$\text{Heifers in confinement} = 95 * (40\%) = 38$$

2. When not confined, dairy cows are on the pasture or in the stream.

$$\text{Milk cows on pasture and in the stream} = (96 - 72) = 24$$

$$\text{Dry cows on pasture and in the stream} = (20 - 8) = 12$$

$$\text{Heifers on pasture and in the stream} = (95 - 38) = 57$$

3. Twenty-seven percent of the pasture acreage has stream access (dairy cows are assumed to graze only on Pasture 1 for this example). Hence dairy cattle with stream access are calculated as:

$$\text{Milk cows on pastures with stream access} = 24 * (27\%) = 6.5$$

$$\text{Dry cows on pastures with stream access} = 12 * (27\%) = 3.2$$

$$\text{Heifers on pastures with stream access} = 57 * (27\%) = 15.4$$

4. Dairy cattle in and around the stream are calculated using the numbers in Step 3 and the number of hours cattle spend in the stream in January as:

$$\text{Milk cows in and around streams} = 6.5 * (0.5/24) = 0.14$$

$$\text{Dry cows in and around streams} = 3.2 * (0.5/24) = 0.07$$

$$\text{Heifers in and around streams} = 15.4 * (0.5/24) = 0.32$$

5. Number of cattle defecating in the stream is calculated by multiplying the number of cattle in and around the stream by 30%:

$$\text{Milk cows defecating in streams} = 0.14 * (30\%) = 0.04$$

$$\text{Dry cows defecating in streams} = 0.07 * (30\%) = 0.02$$

$$\text{Heifers defecating in streams} = 0.32 * (30\%) = 0.10$$

6. After calculating the number of cattle defecating in the stream, the number of cattle defecating on the pasture is calculated by subtracting the number of cattle defecating in the stream (Step 5) from number of cattle in pasture and stream (Step 2).

$$\text{Milk cows defecating on pasture} = (24 - 0.04) = 23.96$$

$$\text{Dry cows defecating on pasture} = (12 - 0.02) = 11.98$$

$$\text{Heifers defecating on pasture} = (57 - 0.10) = 56.90$$

Appendix C. Die-off Fecal Coliform During Storage

Die-off of Fecal Coliform During Storage

The following procedure was used to calculate amount of fecal coliform produced in confinement in dairy manure applied to cropland and pasture. All calculations were performed on spreadsheet for each sub watershed with dairy operations in a watershed.

1. It was determined from a producer survey in Rockingham County that 15% of the dairy farms had dairy manure storage for less than 30 days; 10% of the dairy farms had storage capacities of 60 days, while the remaining operations had 180-day storage capacity. Using a decay rate of 0.375 for liquid dairy manure, the die-off of fecal coliform in different storage capacities at the ends of the respective storage periods were calculated using Eq. [5.1]. Based on the fractions of different storage capacities, a weighted average die-off was calculated for all dairy manure.
2. Based on fecal coliform die-off, the surviving fraction of fecal coliform at the end of storage period was estimated to be 0.0078 in dairy manure.
3. The annual production of fecal coliform based on 'as-excreted' values was calculated for dairy manure.
4. The annual fecal coliform production from dairy manure was multiplied by the fraction of surviving fecal coliform to obtain the amount of fecal coliform that was available for land application on annual basis. For monthly application, the annual figure was multiplied by the fraction of dairy applied during that month based on the application schedule given in Table 19. Schedule of cattle and poultry waste application in the Licking and Cedar Run watersheds.

Appendix D. HSPF Parameters that Vary by Month or Land Use

Table D1. PWAT-PARM2 and PARM4 parameters that vary by land use for Cedar Run and Licking Run.

Land Use	LZSN	LSUR	SLSUR	NSUR
	(in)	(ft)		
Crops	8.5	358.9	0.04	0.25
Pasture	8.5	353.3	0.04	0.25
Low Density Residential	8.5	340.4	0.05	0.15
High Density Residential	8.5	350.6	0.04	0.15
Forest	10.0	336.5	0.05	0.30

Table D2. CEPSC (monthly interception storage capacity, inches) for Cedar Run and Licking Run

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Crops	0.01	0.01	0.085	0.098	0.115	0.118	0.118	0.114	0.115	0.097	0.092	0.01
Pasture	0.03	0.03	0.065	0.078	0.095	0.098	0.098	0.094	0.095	0.077	0.072	0.03
Low Density Residential	0.03	0.03	0.065	0.078	0.095	0.098	0.098	0.094	0.095	0.077	0.072	0.03
High Density Residential	0.03	0.03	0.065	0.078	0.095	0.098	0.098	0.094	0.095	0.077	0.072	0.03
Forest	0.03	0.03	0.10	0.14	0.20	0.20	0.20	0.20	0.20	0.14	0.10	0.03

Table D3. UZSN (monthly upper zone storage, inches) for Cedar Run and Licking Run

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Crops	0.40	0.40	0.40	0.60	0.80	0.90	0.90	0.90	0.6	0.4	0.40	0.40
Pasture	0.50	0.50	0.50	0.70	0.80	0.80	0.80	0.80	0.70	0.50	0.50	0.50
Low Density Residential	0.40	0.40	0.40	0.60	0.80	0.80	0.80	0.80	0.60	0.40	0.40	0.40
High Density Residential	0.40	0.40	0.40	0.60	0.80	0.80	0.80	0.80	0.60	0.40	0.40	0.40
Forest	0.60	0.60	0.60	0.70	1.40	1.50	1.50	1.50	0.70	0.60	0.60	0.60

Table D4. LZETP (monthly lower zone evapotranspiration factor) for Cedar Run and Licking Run

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Crops	0.1	0.1	0.1	0.1	0.55	0.8	0.8	0.8	0.7	0.55	0.15	0.1
Pasture	0.1	0.1	0.1	0.3	0.55	0.8	0.8	0.8	0.7	0.55	0.15	0.1
Low Density Residential	0.2	0.2	0.3	0.3	0.55	0.8	0.8	0.8	0.7	0.55	0.2	0.2
High Density Residential	0.2	0.2	0.3	0.3	0.55	0.8	0.8	0.8	0.7	0.55	0.2	0.2
Forest	0.1	0.1	0.3	0.4	0.8	0.9	0.9	0.9	0.8	0.6	0.4	0.2

Table D5. SQO (initial storage on surface) for Cedar Run and Licking Run.

	CER-01	CER-02	CER-03	CER-04	CER-05	CER-06	CER-07	CER-08	CER-09
Forest	6.E+08	5.E+08	5.E+08	2.E+09	2.E+09	3.E+08	9.E+08	9.E+07	4.E+08
Crops	7.E+08	8.E+08	8.E+08	9.E+08	8.E+08	7.E+08	1.E+09	1.E+08	7.E+08
Pasture	5.E+10	8.E+10	7.E+10	8.E+10	5.E+10	2.E+11	2.E+11	2.E+10	3.E+11
LDR	2.E+09	2.E+10	5.E+09	5.E+09	6.E+09	2.E+09	2.E+09	5.E+08	2.E+09
HDR	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00

Table D6. ACQOP (monthly accumulation rate for fecal coliform) for Cedar Run and Licking Run

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
***CER-1												
Crop	4.00E+07	8.00E+07	2.00E+08	2.00E+08	7.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	8.00E+07	9.00E+07	4.00E+07
Pasture	3.00E+09	3.00E+09	6.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	6.00E+09	6.00E+09	5.00E+09	3.00E+09
LDR	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Forest	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07
***CER-2												
Crop	5.00E+07	8.00E+07	2.00E+08	2.00E+08	8.00E+07	5.00E+07	5.00E+07	5.00E+07	5.00E+07	9.00E+07	9.00E+07	5.00E+07
Pasture	8.00E+09	8.00E+09	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	7.00E+09
LDR	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Forest	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07
***CER-3												
Crop	3.00E+07	9.00E+07	3.00E+08	2.00E+08	9.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	9.00E+07	1.00E+08	3.00E+07
Pasture	5.00E+09	5.00E+09	9.00E+09	9.00E+09	1.00E+10	1.00E+10	1.00E+10	1.00E+10	8.00E+09	8.00E+09	8.00E+09	5.00E+09
LDR	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08
HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Forest	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07
***CER-4												
Crop	4.00E+07	9.00E+07	3.00E+08	3.00E+08	9.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	9.00E+07	1.00E+08	4.00E+07
Pasture	6.00E+09	6.00E+09	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	5.00E+09
LDR	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08
HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Forest	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
***CER-5												
Crop	4.00E+07	9.00E+07	2.00E+08	2.00E+08	8.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	1.00E+08	1.00E+08	4.00E+07
Pasture	4.00E+09	4.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	7.00E+09	5.00E+09	5.00E+09	5.00E+09	3.00E+09
LDR	7.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08
HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Forest	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
***CER-6												

Crop	3.00E+07	7.00E+07	2.00E+08	2.00E+08	6.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	8.00E+07	8.00E+07	3.00E+07
Pasture	1.00E+10	1.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	1.00E+10
LDR	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
HDR	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07
Forest													
***CER-7													
Crop	3.00E+07	1.00E+08	4.00E+08	3.00E+08	1.00E+08	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	9.00E+07	1.00E+08	3.00E+07
Pasture	1.00E+10	1.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	2.00E+10	1.00E+10
LDR	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Forest	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08
***CER-8													
A.1. Crop	8.00E+06	1.00E+07	4.00E+07	3.00E+07	1.00E+07	8.00E+06	8.00E+06	8.00E+06	8.00E+06	8.00E+06	2.00E+07	2.00E+07	8.00E+06
Pasture	1.00E+09	1.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	1.00E+09
LDR	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07
HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Forest	1.00E+07	1.00E+07	1.00E+07	1.00E+07	1.00E+07	1.00E+07	1.00E+07	1.00E+07	1.00E+07	1.00E+07	1.00E+07	1.00E+07	1.00E+07
***CER-9													
Crop	4.00E+07	7.00E+07	2.00E+08	2.00E+08	7.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	7.00E+07	9.00E+07	4.00E+07
Pasture	2.00E+10	2.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	5.00E+10	5.00E+10	4.00E+10	4.00E+10	4.00E+10	2.00E+10
LDR	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Forest	4.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07

Table D7. SQOLIM Table for Cedar Run and Licking Run

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
*** CER-1												
Crop	4.00E+08	7.00E+08	2.00E+09	2.00E+09	6.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	7.00E+08	8.00E+08	4.00E+08
Pasture	3.00E+10	3.00E+10	5.00E+10	6.00E+10	6.00E+10	6.00E+10	6.00E+10	6.00E+10	5.00E+10	5.00E+10	5.00E+10	3.00E+10
LDR	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Forest	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08
*** CER-2												
Crop	5.00E+08	7.00E+08	2.00E+09	2.00E+09	7.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	8.00E+08	8.00E+08	5.00E+08
Pasture	7.00E+10	7.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	6.00E+10
LDR	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10
HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Forest	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08
*** CER-3												
Crop	3.00E+08	8.00E+08	3.00E+09	2.00E+09	8.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	8.00E+08	9.00E+08	3.00E+08
Pasture	5.00E+10	5.00E+10	8.00E+10	8.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	7.00E+10	7.00E+10	7.00E+10	5.00E+10
LDR	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09
HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Forest	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08
*** CER-4												
Crop	4.00E+08	8.00E+08	3.00E+09	3.00E+09	8.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	8.00E+08	9.00E+08	4.00E+08
Pasture	5.00E+10	5.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	5.00E+10
LDR	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09
HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Forest	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
*** CER-5												
Crop	4.00E+08	8.00E+08	2.00E+09	2.00E+09	7.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	9.00E+08	9.00E+08	4.00E+08
Pasture	4.00E+10	4.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	6.00E+10	5.00E+10	5.00E+10	5.00E+10	3.00E+10
LDR	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09
HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Forest	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
*** CER-6												
Crop	3.00E+08	6.00E+08	2.00E+09	2.00E+09	5.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	7.00E+08	7.00E+08	3.00E+08
Pasture	9.00E+10	9.00E+10	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	9.00E+10

LDR	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
HDR	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08
*** CER-7													
Crop	3.00E+08	9.00E+08	4.00E+09	3.00E+09	9.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	8.00E+08	9.00E+08	3.00E+08
Pasture	9.00E+10	9.00E+10	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	2.00E+11	9.00E+10
LDR	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Forest	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08
*** CER-8													
Crop	7.00E+07	9.00E+07	4.00E+08	3.00E+08	9.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	2.00E+08	2.00E+08	7.00E+07
Pasture	9.00E+09	9.00E+09	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	9.00E+09
LDR	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08
HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Forest	9.00E+07	9.00E+07	9.00E+07	9.00E+07	9.00E+07	9.00E+07	9.00E+07	9.00E+07	9.00E+07	9.00E+07	9.00E+07	9.00E+07	9.00E+07
*** CER-9													
Crop	4.00E+08	6.00E+08	2.00E+09	2.00E+09	6.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	6.00E+08	8.00E+08	4.00E+08
Pasture	2.00E+11	2.00E+11	4.00E+11	4.00E+11	4.00E+11	4.00E+11	5.00E+11	5.00E+11	4.00E+11	4.00E+11	4.00E+11	4.00E+11	2.00E+11
LDR	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Forest	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08

Appendix E. Fecal Coliform Loading in Sub-Watersheds

Table E.1. Monthly nonpoint fecal coliform loadings in sub-watershed CER-01.

	Fecal Coliform loadings ($\times 10^{10}$ cfu/month)			
Month	Cropland	Pasture	Forest	Residential
Jan	360	24,124	1,853	1,493
Feb	630	22,320	1,688	1,361
Mar	1,870	42,512	1,853	1,493
Apr	1,556	43,588	1,793	1,445
May	662	45,617	1,853	1,493
Jun	349	44,591	1,793	1,445
Jul	360	46,687	1,853	1,493
Aug	360	47,297	1,853	1,493
Sep	349	36,592	1,793	1,445
Oct	672	38,608	1,853	1,493
Nov	808	36,246	1,793	1,445
Dec	360	22,285	1,853	1,493
Total	8,335	450,466	21,827	17,597

Table E.2. Monthly nonpoint fecal coliform loadings in sub-watershed CER-02.

	Fecal Coliform loadings ($\times 10^{10}$ cfu/month)			
Month	Cropland	Pasture	Forest	Residential
Jan	147	11,548	2,021	233
Feb	208	10,702	1,842	212
Mar	514	19,212	2,021	233
Apr	436	18,884	1,956	225
May	221	19,788	2,021	233
Jun	143	19,263	1,956	225
Jul	147	20,226	2,021	233
Aug	147	20,547	2,021	233
Sep	143	15,143	1,956	225
Oct	259	16,094	2,021	233
Nov	254	15,989	1,956	225
Dec	147	10,569	2,021	233
Total	2,767	197,966	23,813	2,742

Table E.3. Monthly nonpoint fecal coliform loadings in sub-watershed CER-03.

	Fecal Coliform loadings ($\times 10^{10}$ cfu/month)			
Month	Cropland	Pasture	Forest	Residential
Jan	312	38,013	1,097	671
Feb	736	35,144	1,000	611
Mar	2,574	67,405	1,097	671
Apr	2,111	68,598	1,062	649
May	764	71,739	1,097	671
Jun	302	70,056	1,062	649
Jul	312	73,306	1,097	671
Aug	312	74,220	1,097	671
Sep	302	58,097	1,062	649
Oct	802	61,236	1,097	671
Nov	990	57,891	1,062	649
Dec	312	35,253	1,097	671
Total	9,828	710,959	12,924	7,906

Table E.4. Monthly nonpoint fecal coliform loadings in sub-watershed CER-04.

	Fecal Coliform loadings ($\times 10^{10}$ cfu/month)			
Month	Cropland	Pasture	Forest	Residential
Jan	738	77,377	3,688	2,810
Feb	1,753	71,295	3,360	2,561
Mar	6,141	138,513	3,688	2,810
Apr	5,036	142,500	3,569	2,720
May	1,818	148,517	3,688	2,810
Jun	714	144,473	3,569	2,720
Jul	738	150,709	3,688	2,810
Aug	738	152,129	3,688	2,810
Sep	714	126,117	3,569	2,720
Oct	1,817	132,247	3,688	2,810
Nov	2,358	122,630	3,569	2,720
Dec	738	73,085	3,688	2,810
Total	23,302	1,479,592	43,448	33,110

Table E.5. Monthly nonpoint fecal coliform loadings in sub-watershed CER-05.

	Fecal Coliform loadings (x10 ¹⁰ cfu/month)			
Month	Cropland	Pasture	Forest	Residential
Jan	274	44,771	6,920	6,900
Feb	528	41,470	6,306	6,288
Mar	1,667	73,985	6,920	6,900
Apr	1,380	72,762	6,697	6,678
May	553	76,365	6,920	6,900
Jun	265	74,896	6,697	6,678
Jul	274	78,614	6,920	6,900
Aug	274	79,836	6,920	6,900
Sep	265	58,785	6,697	6,678
Oct	698	62,315	6,920	6,900
Nov	689	61,808	6,697	6,678
Dec	274	41,090	6,920	6,900
Total	7,140	766,699	81,531	81,303

Table E.6. Monthly nonpoint fecal coliform loadings in sub-watershed CER-06.

	Fecal Coliform loadings (x10 ¹⁰ cfu/month)			
Month	Cropland	Pasture	Forest	Residential
Jan	54	6,996	58	84
Feb	95	6,487	53	76
Mar	286	11,825	58	84
Apr	238	11,615	56	81
May	100	12,152	58	84
Jun	52	11,747	56	81
Jul	54	12,337	58	84
Aug	54	12,535	58	84
Sep	52	9,269	56	81
Oct	124	9,873	58	84
Nov	123	9,821	56	81
Dec	54	6,385	58	84
Total	1,286	121,045	686	985

Table E.7. Monthly nonpoint fecal coliform loadings in sub-watershed CER-07.

	Fecal Coliform loadings (x10 ¹⁰ cfu/month)			
Month	Cropland	Pasture	Forest	Residential
Jan	286	22,940	1,085	371
Feb	791	20,961	988	338
Mar	2,937	45,432	1,085	371
Apr	2,398	48,534	1,050	359
May	816	50,204	1,085	371
Jun	276	48,489	1,050	359
Jul	286	50,207	1,085	371
Aug	286	50,309	1,085	371
Sep	276	47,326	1,050	359
Oct	738	49,080	1,085	371
Nov	1,083	43,151	1,050	359
Dec	286	22,634	1,085	371
Total	10,458	499,265	12,780	4,372

Table E.8. Monthly nonpoint fecal coliform loadings in sub-watershed CER-08.

	Fecal Coliform loadings (x10 ¹⁰ cfu/month)			
Month	Cropland	Pasture	Forest	Residential
Jan	41	5,275	126	179
Feb	69	4,874	115	163
Mar	198	8,539	126	179
Apr	165	8,380	122	173
May	72	8,779	126	179
Jun	40	8,600	122	173
Jul	41	9,009	126	179
Aug	41	9,131	126	179
Sep	40	6,983	122	173
Oct	89	7,372	126	179
Nov	87	7,284	122	173
Dec	41	4,907	126	179
Total	923	89,134	1,490	2,112

Table E.9. Monthly nonpoint fecal coliform loadings in sub-watershed CER-09.

	Fecal Coliform loadings (x10 ¹⁰ cfu/month)			
Month	Cropland	Pasture	Forest	Residential
Jan	1,047	100,826	1,464	1,135
Feb	1,901	93,223	1,334	1,034
Mar	5,782	169,517	1,464	1,135
Apr	4,802	170,683	1,417	1,099
May	1,994	178,725	1,464	1,135
Jun	1,013	174,939	1,417	1,099
Jul	1,047	183,215	1,464	1,135
Aug	1,047	185,660	1,464	1,135
Sep	1,013	142,722	1,417	1,099
Oct	2,148	150,625	1,464	1,135
Nov	2,454	144,465	1,417	1,099
Dec	1,047	93,465	1,464	1,135
Total	25,296	1,788,066	17,249	13,375

**Appendix F. Required Reductions in Fecal Coliform Loads by
Sub-Watershed – Allocation Scenario**

Table F.1a. Required annual reductions in nonpoint sources in sub watershed CER-01 of the Cedar Run watershed.

Land use	Current conditions load (x 10 ⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cropland	833,493	2%	833,493	0%
Pasture	45,046,573	90%	2,252,329	95%
Forest	2,182,725	4%	2,182,725	0%
Residential	1,759,665	4%	87,983	95%
Total	49,822,456	100%	5,356,530	89%

Table F.1b. Required annual reductions in direct nonpoint sources in sub watershed CER-01 of the Cedar Run watershed.

Source	Current Conditions load (x 10 ⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cattle in stream	127,914	60%	1,279	99%
Wildlife in stream	86,403	40%	4,320	95%
Total	214,317	100%	5,599	97%

Table F.2a. Required annual reductions in nonpoint sources in sub watershed CER-02 of the Cedar Run watershed.

Land use	Current conditions load (x 10 ⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cropland	276,667	1%	276,667	0%
Pasture	19,796,591	87%	989,830	95%
Forest	2,381,325	10%	2,381,325	0%
Residential	274,157	1%	13,708	95%
Total	22,728,740	100%	3,661,530	84%

Table F.2b. Required annual reductions in direct nonpoint sources in sub watershed CER-02 of the Cedar Run watershed.

Source	Current Conditions load (x 10 ⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cattle in stream	175,810	65%	1,758	99%
Wildlife in stream	95,400	35%	4,770	95%
Total	271,210	100%	6,528	98%

Table F.3a. Required annual reductions in nonpoint sources in sub watershed CER-03 of the Cedar Run watershed.

Land use	Current conditions load (x 10 ⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cropland	982,812	1%	982,812	0%
Pasture	71,095,868	96%	3,554,793	95%
Forest	1,292,443	2%	1,292,443	0%
Residential	790,584	1%	39,529	95%
Total	74,161,706	100%	5,869,577	92%

Table F.3b. Required annual reductions in direct nonpoint sources in sub watershed CER-03 of the Cedar Run watershed.

Source	Current Conditions load (x 10 ⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cattle in stream	224,984	81%	2,250	99%
Wildlife in stream	52,528	19%	2,626	95%
Total	277,512	100%	4,876	98%

Table F.4a. Required annual reductions in nonpoint sources in sub watershed CER-04 of the Cedar Run watershed.

Land use	Current conditions load (x 10 ⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cropland	2,330,230	1%	2,330,230	0%
Pasture	147,959,159	94%	7,397,958	95%
Forest	4,344,817	3%	4,344,817	0%
Residential	3,311,028	2%	165,551	95%
Total	157,945,233	100%	14,238,556	91%

Table F.4b. Required annual reductions in direct nonpoint sources in sub watershed CER-04 of the Cedar Run watershed.

Source	Current Conditions load (x 10 ⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cattle in stream	558,219	69%	5,582	99%
Wildlife in stream	245,878	31%	12,294	95%
Total	804,096	100%	17,876	98%

Table F.5a. Required annual reductions in nonpoint sources in sub watershed CER-05 of the Cedar Run watershed.

Land use	Current conditions load (x 10 ⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cropland	714,022	1%	714,022	0%
Pasture	76,669,857	82%	3,833,493	95%
Forest	8,153,097	9%	8,153,097	0%
Residential	8,130,282	9%	406,514	95%
Total	93,667,258	100%	13,107,126	86%

Table F.5b. Required annual reductions in direct nonpoint sources in sub watershed CER-05 of the Cedar Run watershed.

Source	Current Conditions load (x 10 ⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cattle in stream	167,585	26%	1,676	99%
Wildlife in stream	482,661	74%	24,133	95%
Total	650,246	100%	25,809	96%

Table F.6a. Required annual reductions in nonpoint sources in sub watershed CER-06 of the Cedar Run/Licking Run watersheds.

Land use	Current conditions load (x 10 ⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cropland	128,627	1%	128,627	0%
Pasture	12,104,507	98%	605,225	95%
Forest	68,647	1%	68,647	0%
Residential	98,471	1%	98,471	0%
Total	12,400,253	100%	900,971	93%

Table F.6b. Required annual reductions in direct nonpoint sources in sub watershed CER-06 of the Cedar Run/Licking Run watersheds.

Source	Current Conditions load (x 10 ⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cattle in stream	182,774	99%	1,828	99%
Wildlife in stream	1,158	1%	116	90%
Total	183,932	100%	1,944	99%

Table F.7a. Required annual reductions in nonpoint sources in sub watershed CER-07 of the Cedar Run/Licking Run watersheds.

Land use	Current conditions load (x 10 ⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cropland	1,045,750	2%	1,045,750	0%
Pasture	49,926,534	95%	2,496,327	95%
Forest	1,278,011	2%	1,278,011	0%
Residential	437,204	1%	437,204	0%
Total	52,687,499	100%	5,257,292	90%

Table F.7b. Required annual reductions in direct nonpoint sources in sub watershed CER-07 of the Cedar Run/Licking Run watersheds.

Source	Current Conditions load (x 10 ⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cattle in stream	171,928	71%	1,719	99%
Wildlife in stream	70,512	29%	7,051	90%
Total	242,440	100%	8,770	96%

Table F.8a. Required annual reductions in nonpoint sources in sub watershed CER-08 of the Cedar Run/Licking Run watersheds.

Land use	Current conditions load (x 10 ⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cropland	92,306	1%	92,306	0%
Pasture	8,913,442	95%	445,672	95%
Forest	148,981	2%	148,981	0%
Residential	211,224	2%	211,224	0%
Total	9,365,952	100%	898,183	90%

Table F.8b. Required annual reductions in direct nonpoint sources in sub watershed CER-08 of the Cedar Run/Licking Run watersheds.

Source	Current Conditions load (x 10 ⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cattle in stream	12,591	73%	126	99%
Wildlife in stream	4,720	27%	472	90%
Total	17,312	100%	598	97%

Table F.9a. Required annual reductions in nonpoint sources in sub watershed CER-09 of the Cedar Run watershed.

Land use	Current conditions load (x 10 ⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cropland	2,529,642	1%	2,529,642	0%
Pasture	178,806,628	97%	8,940,331	95%
Forest	1,724,911	1%	1,724,911	0%
Residential	1,337,472	1%	66,874	95%
Total	184,398,654	100%	13,261,758	93%

Table F.9b. Required annual reductions in direct nonpoint sources in sub watershed CER-09 of the Cedar Run watershed.

Source	Current Conditions load (x 10 ⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10 ⁸ cfu/year)	Percent reduction
Cattle in stream	342,913	90%	3,429	99%
Wildlife in stream	37,643	10%	1,882	95%
Total	380,556	100%	5,311	99%

**Appendix G. Simulated Stream Flow Chart for TMDL Allocation
Period**

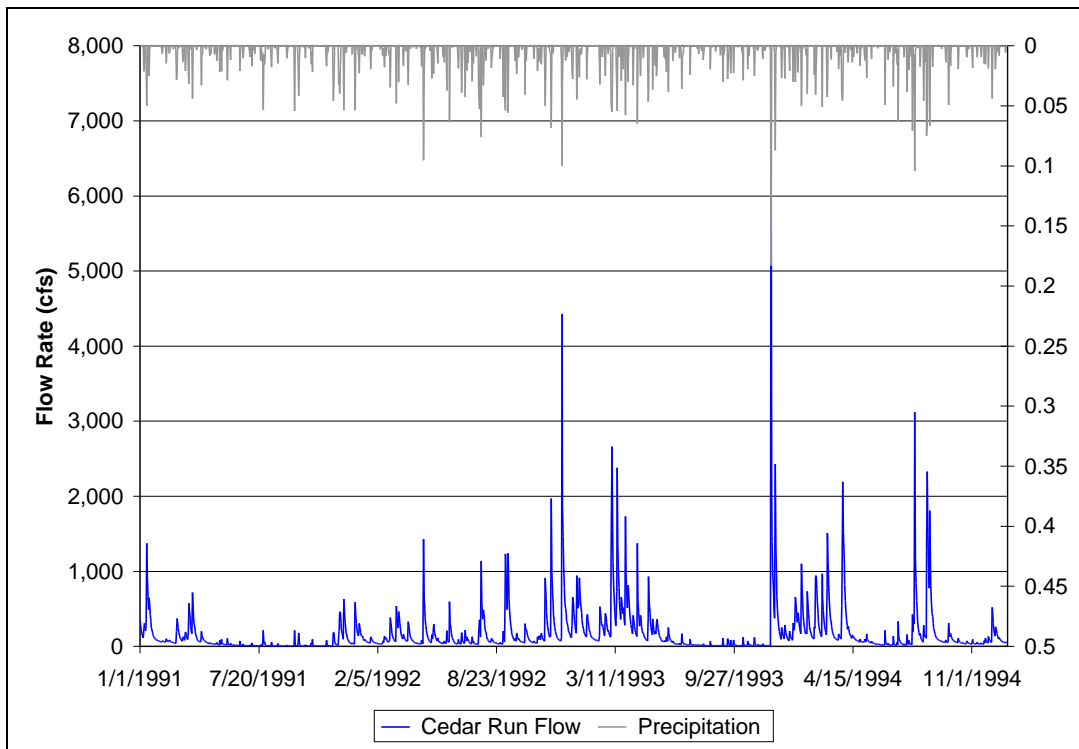


Figure G.1. Simulated Stream Flow for Cedar Run TMDL Allocation Period.

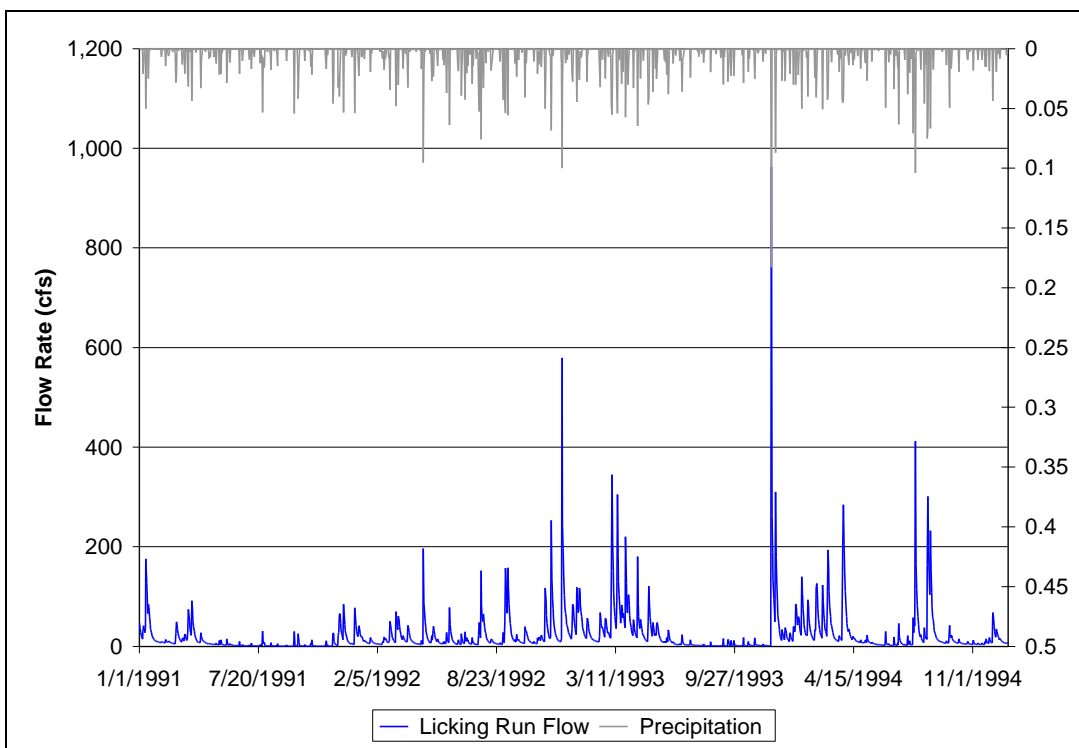
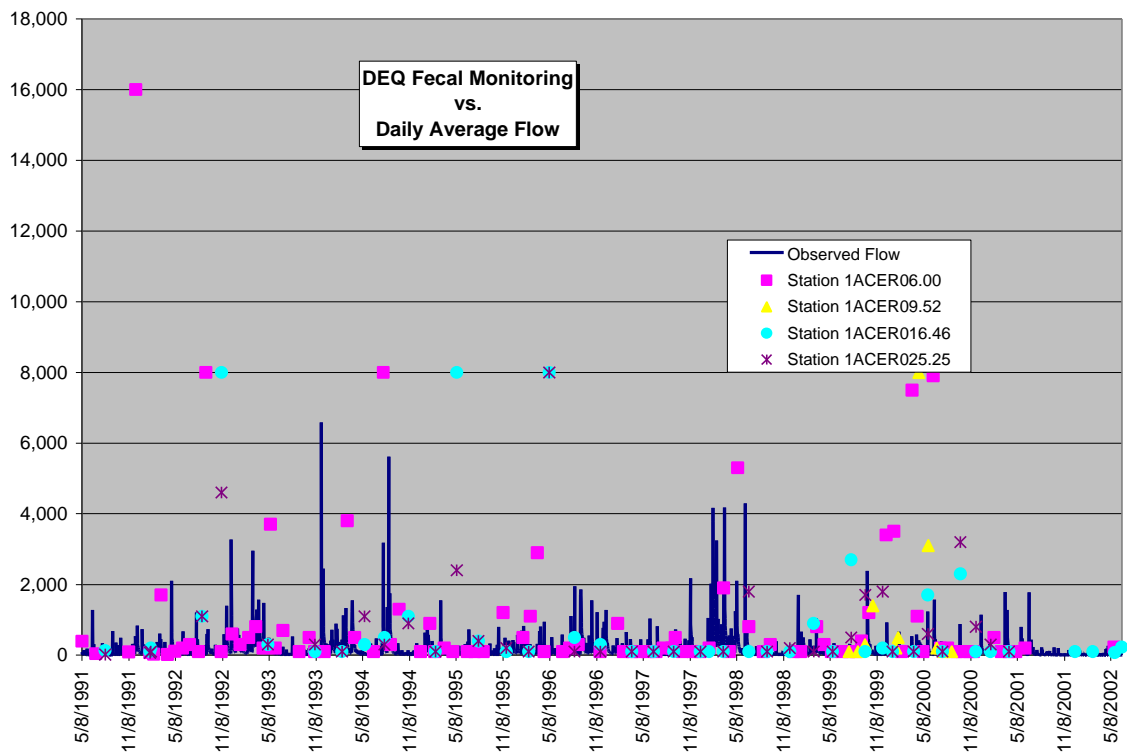
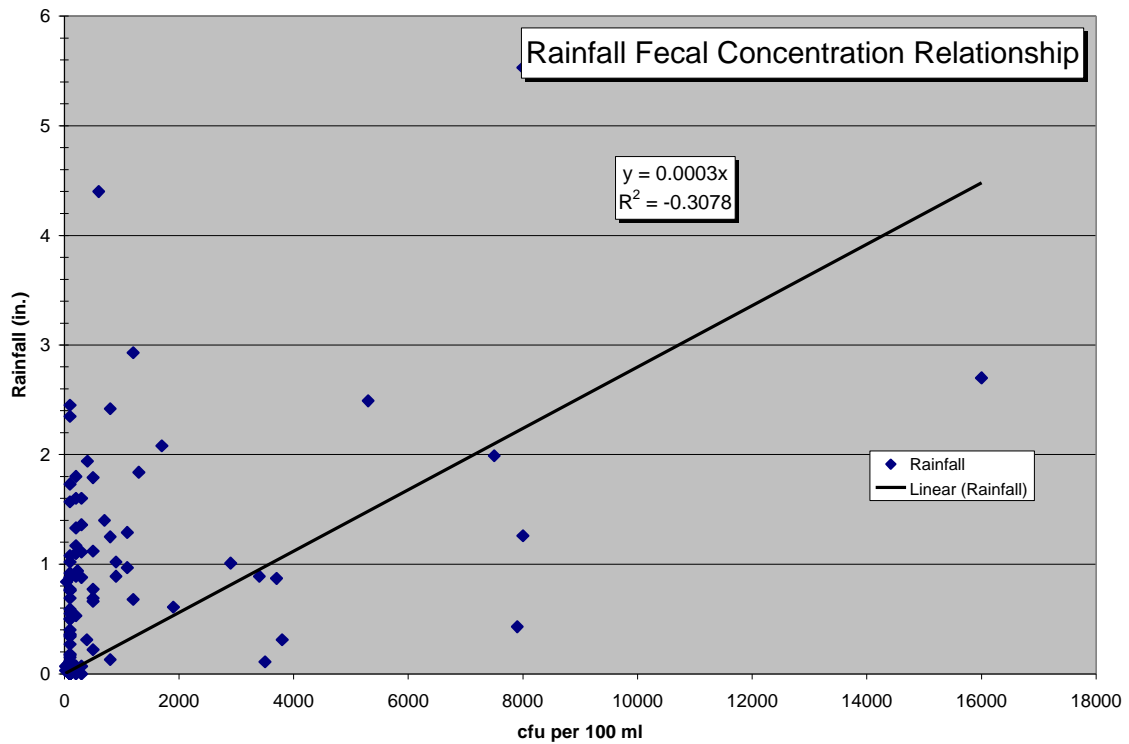
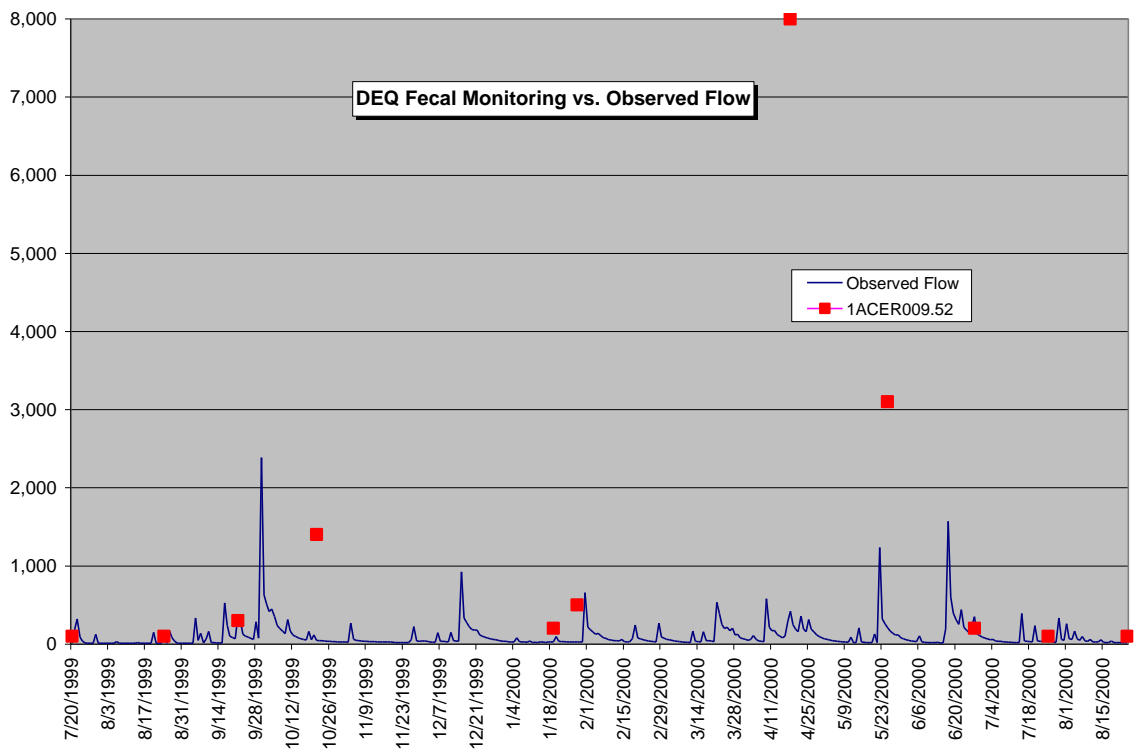
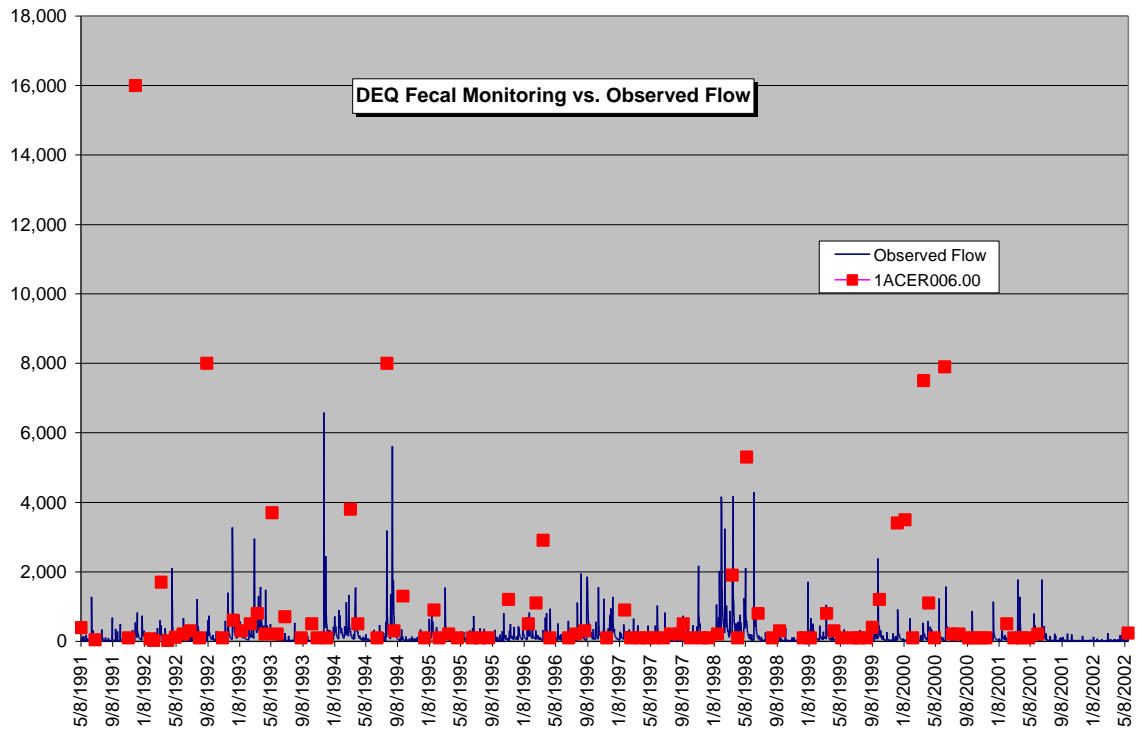
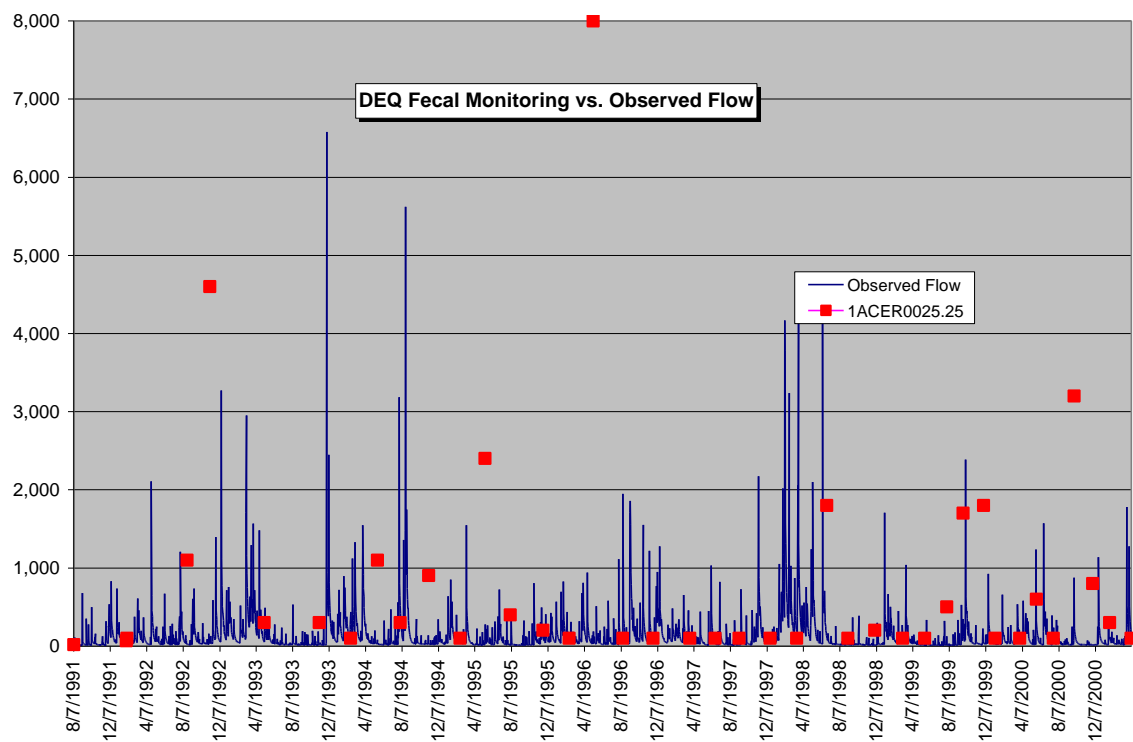
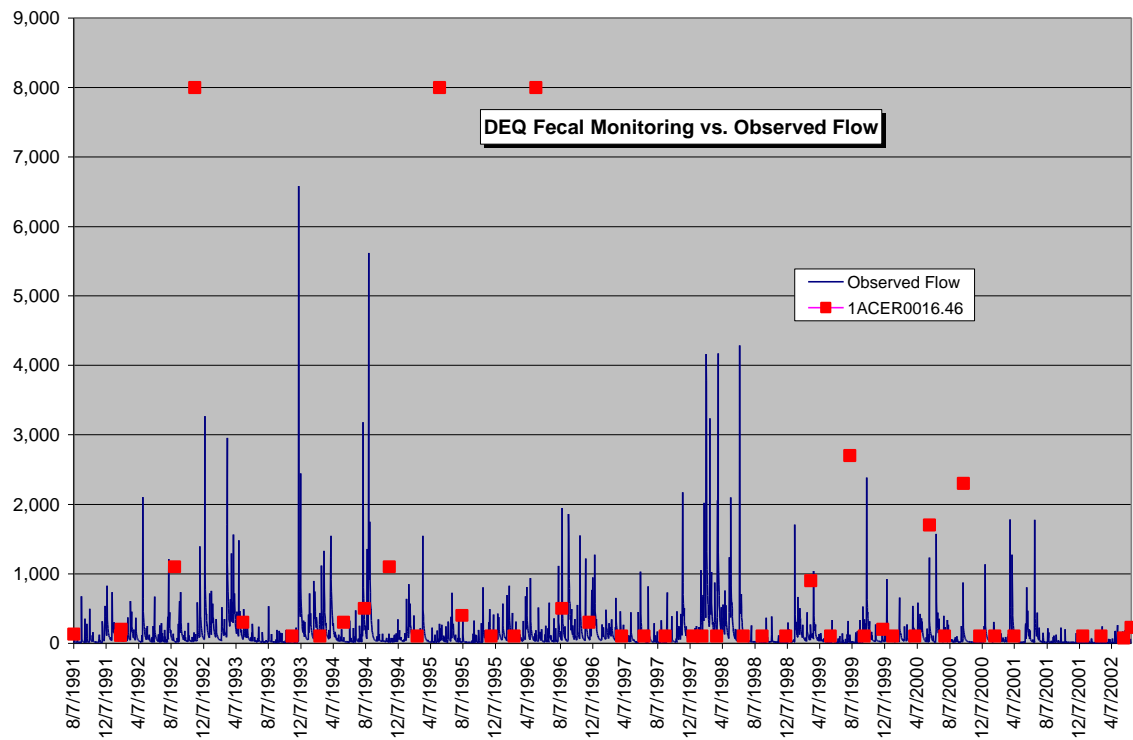


Figure G.2. Simulated Stream Flow for Licking Run TMDL Allocation Period.

Appendix H. Observed Fecal Coliform Concentrations and Antecedent Rainfall







**Appendix I. Scenarios for Fivefold Increase in Permitted
Discharge Flows**

To allow for future growth, scenarios were created for the Cedar Run and Licking Run watersheds in which the point source flows were increased by a factor of 5, while retaining the 200 cfu/100 mL limit on bacteria. Loads from MS4 areas were not altered. This effectively increased the WLA by a factor of 5 for permitted point sources. Figures 1 and 2 display the results for Licking Run and Cedar Run, respectively. The TMDL equations that would represent these situations are included in Table I-1.

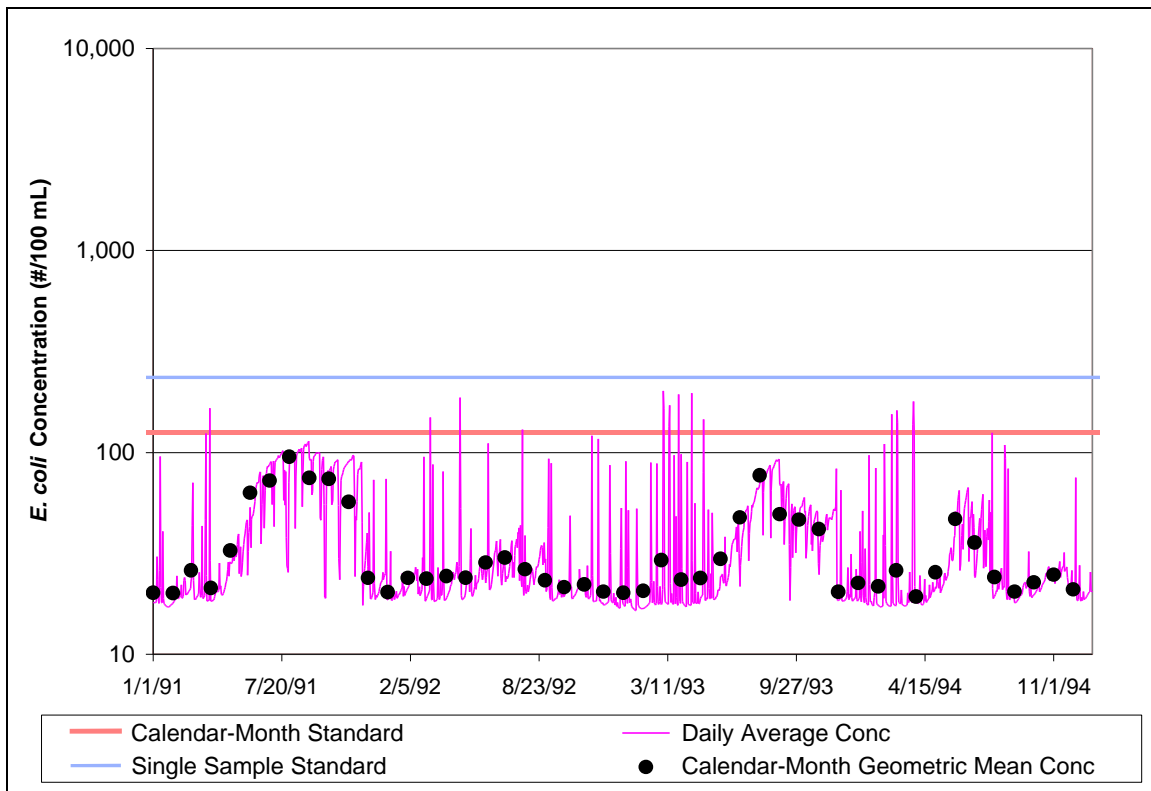


Figure I-1. Daily average and calendar-month geometric mean *E. coli* concentration in the Licking Run watershed under the fivefold WLA increase scenario.

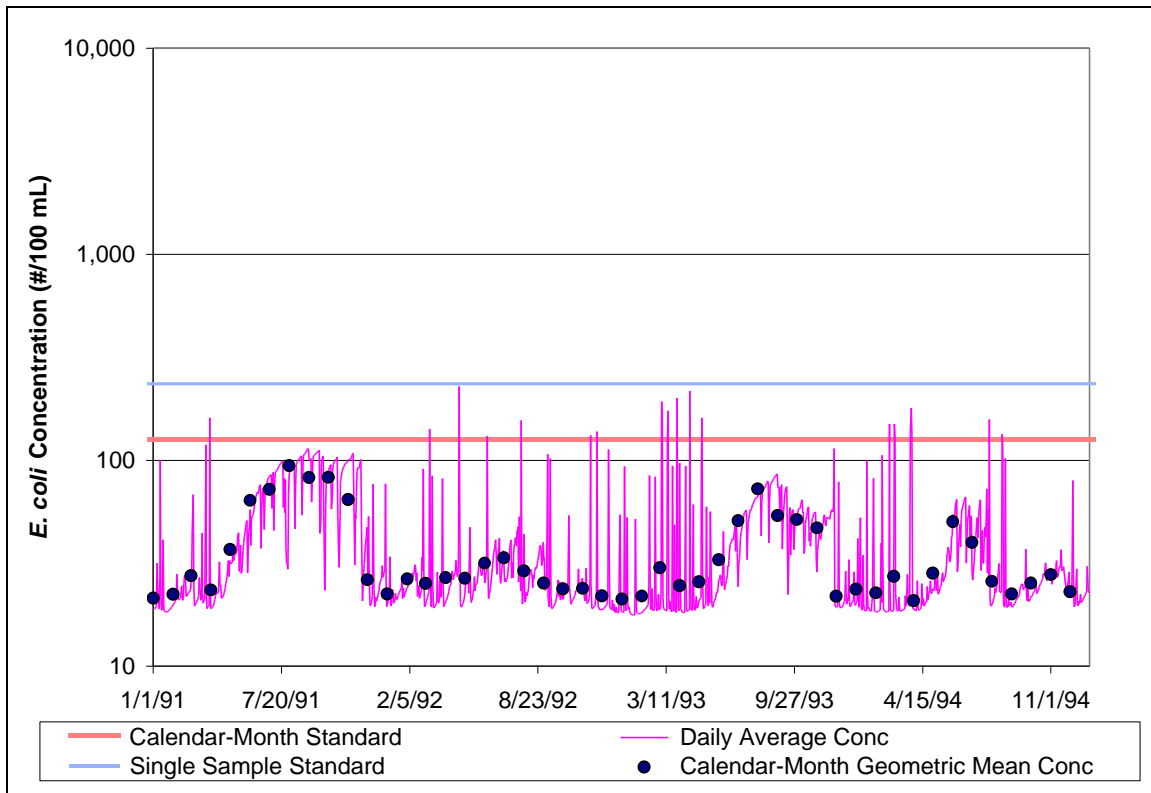


Figure I-2. Daily average and calendar-month geometric mean *E. coli* concentration in the Cedar Run watershed under the fivefold WLA increase scenario.

Table I-1. Average annual *E. coli* loadings (cfu/year) at the watershed outlet for the Licking Run and Cedar Run watersheds under the fivefold WLA increase scenario.

Watershed	SWLA	SLA	TMDL
Licking Run	1.3×10^{10}	968×10^{10}	970×10^{10}
Cedar Run without Licking Run	184×10^{10}	$6,975 \times 10^{10}$	$7,160 \times 10^{10}$
Cedar Run with Licking Run	185×10^{10}	$7,944 \times 10^{10}$	$8,129 \times 10^{10}$

As can be seen from the graphs, the new scenarios result in no violations of the instantaneous or geometric mean standards. Therefore, it is assumed that future growth in point source dischargers with a consistent permitted bacteria concentration of 200 cfu/100 mL fecal coliform will not cause additional violations of the water quality standards.

Appendix J. Scenario for Increased Permit Limits at Quantico

An additional concern for the Cedar Run watershed was the imminent increase in permitted discharge from the Quantico facility. The permitted discharge rate at the Quantico facility will increase from 0.14 MGD to 0.44 MGD, with the same 200 cfu/100 mL limit on fecal coliform bacteria concentration.

A scenario was created to allow for the future expansion of the Quantico facility. Because it is located in sub-watershed 2 of Cedar Run, the expansion will not affect Licking Run (and thus new tables and figures for Licking Run are not presented). The successful scenario is presented in Figure J-1.

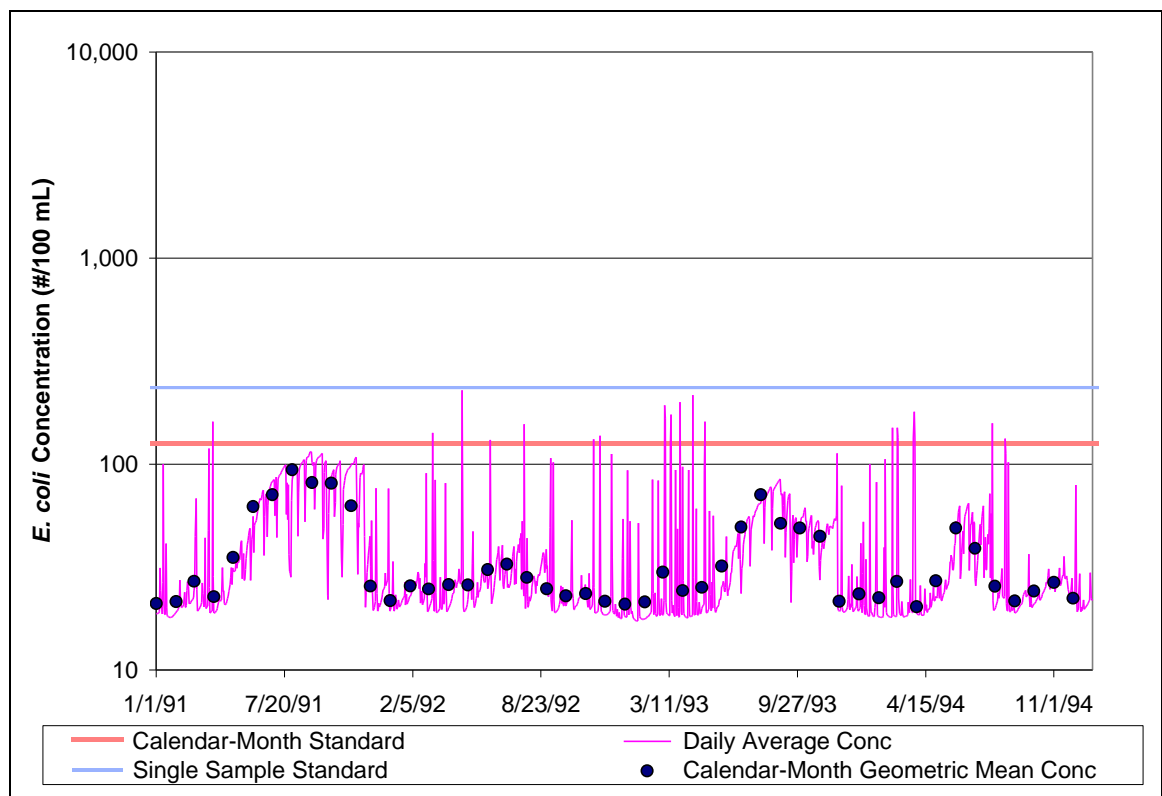


Figure J-1. Daily average and calendar-month geometric mean *E. coli* concentration in the Cedar Run watershed with the expanded Quantico facility scenario.

Table J-1. Annual *E. coli* loadings (cfu/year) at the watershed outlet for Cedar Run with the expanded Quantico facility scenario.

Watershed	Parameter	SWLA	SLA	MOS*	TMDL
<i>Cedar Run Excluding Licking Run</i>	<i>E. coli</i>	101×10^{10} (VA0027278 = 1.38×10^{10} ; VA0028371 = 5.23×10^{11} ; SSFH WLA = 2.09×10^{10} ; SMS4 area = 4.50×10^{11})	$6,984 \times 10^{10}$	--	$7,085 \times 10^{10}$
<i>Cedar Run Including Licking Run</i>	<i>E. coli</i>	101×10^{10} (VA0027278 = 1.38×10^{10} ; VA0028371 = 5.23×10^{11} ; VA0084298 = 2.61×10^9 ; SSFH WLA = 2.09×10^{10} ; SMS4 area = 4.50×10^{11})	$7,953 \times 10^{10}$	--	$8,054 \times 10^{10}$

*Implicit Margin of Safety

As described in the previous appendix, five fold increases in permitted point sources are considered to allow for future growth. In keeping with this allowance, an additional five-fold increase scenario for Cedar Run was considered wherein the Quantico facility had a discharge rate of 5 x 0.44 MGD. All other permitted dischargers had loads increased to five times their current permit levels. Figure J-2 displays the results for Cedar Run with the five-fold increase in the Quantico expansion scenario. The TMDL equations that would represent this situation are included in Table J-2.

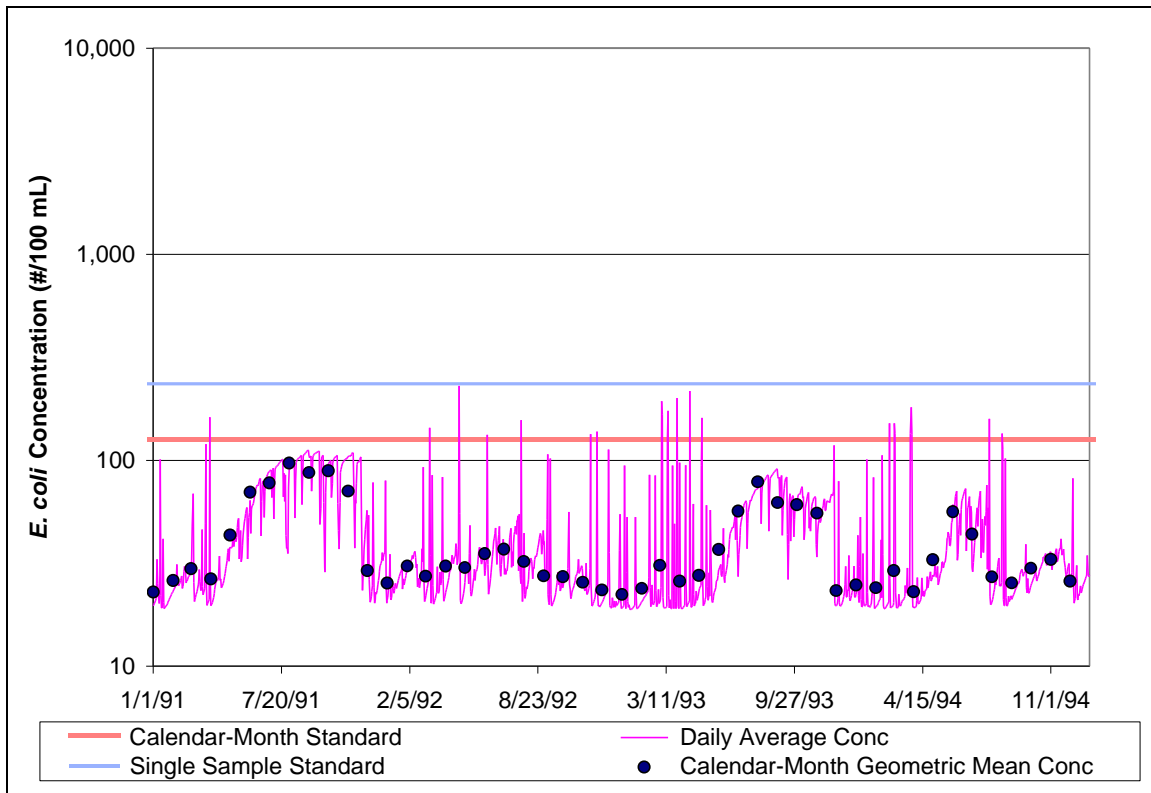


Figure J-2. Daily average and calendar-month geometric mean *E. coli* concentration in the Cedar Run watershed under the fivefold WLA increase scenario with the expanded load at Quantico.

Table J-2. Average annual *E. coli* loadings (cfu/year) at the watershed outlet for the Cedar and Licking Run watersheds with expanded Quantico.

Watershed	SWLA	SLA	TMDL
Cedar Run without Licking Run	184×10^{10}	$7,293 \times 10^{10}$	$7,477 \times 10^{10}$
Cedar Run with Licking Run	185×10^{10}	$8,262 \times 10^{10}$	$8,447 \times 10^{10}$

As can be seen from the graphs, the new scenarios result in no violations of the instantaneous or geometric mean standards. Therefore, it is assumed that future growth in point source dischargers with a consistent permitted bacteria concentration of 200 cfu/100 mL fecal coliform will not cause additional violations of the water quality standards.

Appendix K. Historical Fecal Coliform Monitoring Data

Table K-1. Historical *E. coli* monitoring results (cfu/100 ml) at the Cedar and Licking Run monitoring stations between 1991 and 2002.

	Cedar Run				Licking Run	
	Station 6.00	Station 9.52	Station 16.46	Station 25.25	Station	1.43
5/8/1991	390					
7/1/1991	40					
8/7/1991			130	18		130
11/6/1991	93					
12/4/1991	16000					170
1/29/1992	68		110	68		
2/1/1992			200	100		1800
2/12/1992	20					
3/12/1992	1700					
4/6/1992	18					
5/5/1992	110					
6/4/1992	200					
7/1/1992	300					
8/6/1992	100					
8/19/1992			1100	1100		1000
9/3/1992	8000					
11/2/1992	100					
11/3/1992			8000	4600		8000
12/15/1992	600					
1/14/1993	300					
2/18/1993	500					
3/17/1993	800					
4/15/1993	200					
5/3/1993			300	300		200
5/13/1993	3700					
6/1/1993	200					
7/1/1993	700					
9/2/1993	100					
10/12/1993	500					
11/2/1993	100					
11/3/1993			100	300		1200
12/9/1993	100					
2/16/1994			100	100		100
3/10/1994	3800					
4/7/1994	500					
5/16/1994			300	1100		100
6/20/1994	100					
7/28/1994	8000					
8/1/1994			500	300		800
8/25/1994	300					
9/28/1994	1300					
11/3/1994			1100	900		100
12/20/1994	100					

Units are cfu/100 ml

	Cedar Run				Licking Run
	Station 6.00	Station 9.52	Station 16.46	Station 25.25	Station 1.43
2/14/1995	100				
2/15/1995					
2/16/1995			100	100	5800
3/23/1995	200				
4/26/1995	100				
5/11/1995			8000	2400	8000
6/21/1995	100				
7/20/1995	100				
8/3/1995			400	400	100
8/23/1995	100				
11/8/1995	1200				
11/20/1995			100	200	500
1/24/1996	500				
2/15/1996			100	100	100
2/22/1996	1100				
3/21/1996	2900				
4/15/1996	100				
5/6/1996			8000	8000	8000
6/27/1996	100				
7/24/1996	200				
8/12/1996			500	100	500
8/27/1996	300				
11/20/1996	100				
11/21/1996			300	100	500
1/29/1997	900				
2/20/1997	100				
3/24/1997			100	100	200
3/26/1997	100				
4/23/1997	100				
5/22/1997	100				
6/17/1997			100	100	100
6/27/1997	100				
7/24/1997	200				
8/28/1997	200				
9/4/1997			100	100	600
9/10/1997	500				
10/8/1997	100				
11/18/1997	100				
12/17/1997	100		100	100	400
1/20/1998			100		100
1/21/1998	200				
3/16/1998			100	100	100
3/18/1998	1900				
4/9/1998	100				
5/12/1998	5300				

Units are cfu/100 ml

	Cedar Run				Licking Run
	Station 6.00	Station 9.52	Station 16.46	Station 25.25	Station 1.43
6/24/1998			100	1800	4900
6/25/1998	800				
8/19/1998	100				
9/3/1998			100	100	100
9/16/1998	300				
12/1/1998			100	200	100
12/16/1998	100				
1/13/1999	100				
3/4/1999			900	100	700
3/16/1999	800				
4/14/1999	300				
5/13/1999	100				
5/17/1999			100	100	100
6/25/1999	100				
7/20/1999	100	100			
7/29/1999			2700	500	8000
8/17/1999	100				
8/24/1999		100			
9/8/1999	400				
9/21/1999		300	100		
9/22/1999				1700	2400
10/6/1999	1200				
10/21/1999		1400			
11/29/1999			200	1800	100
12/13/1999	3400				
1/6/2000			100	100	700
1/12/2000	3500				
1/19/2000		200			
1/28/2000		500			
2/10/2000	100				
3/23/2000	7500				
3/29/2000			100	100	300
4/12/2000	1100				
4/18/2000		8000			
5/4/2000	100				
5/23/2000			1700	600	700
5/25/2000		3100			
6/13/2000	7900				
6/27/2000		200			
7/12/2000	200				
7/19/2000			100	100	100
7/25/2000		100			
8/8/2000	200				
8/24/2000		100			
9/13/2000	100				

Units are cfu/100 ml

	Cedar Run				Licking Run
	Station 6.00	Station 9.52	Station 16.46	Station 25.25	Station 1.43
9/27/2000			2300	3200	3000
10/3/2000	100				
11/1/2000	100				
11/18/2000	100				
11/27/2000			100	800	900
1/23/2001			100	300	200
2/6/2001	500				
3/6/2001	100				
4/3/2001	100				
4/4/2001					
4/5/2001			100	100	
4/19/2001					1800
5/1/2001	100				
6/6/2001	200				
12/19/2001			100		
2/26/2002			100		
5/20/2002	230				
5/22/2002			75		
6/19/2002			230		
6/21/2002					100

Units are cfu/100 ml

Appendix L. Biological Source Tracking Analyses, MapTech Report

